FINAL REPORT

for

APOLLO SHIPS INSTRUMENTATION RADAR PROGRAM

(August 1964 - October 1965)

Contract No. NAS 5-9720

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

April 1966

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ABSTRACT

This final report covers the design and development of Radar Set, Model AN/FPS-16(V), Systems 47, 48 and 49. It summarizes the entire program, describing the design approach, developmental history, and the final design. This latest design utilizes, to the maximum extent possible, components and equipments developed for earlier AN/FPS-16 radars. Consequently, this report concentrates on the new designs and innovations developed specifically for this program. Compliance with the specified performance requirements is demonstrated by the data gathered during acceptance tests.

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Section 1

INTRODUCTION

The three Radar Sets AN/FPS-16(V)'s furnished to NASA for the Apollo Ships Program are the latest additions to a long line of highly successful instrumentation radars specifically engineered for test-range applications. Over the past nine years, more than fifty of these equipments including land-based, transportable, and shipboard versions were built. Through constant exposure to the operational requirements and objectives of the test ranges, these instruments have achieved high standards of performance and reliability. In this latest design, many of the performance-proven features of previous equipments have been skillfully blended with a few design innovations to produce an excellent range instrument for this shipboard application.

The primary function of these equipments is to supply metric data in digitized spherical coordinates (referenced to the ship's deck plane) on either cooperative or non-cooperative earth-orbiting targets. This coordinate data is available on a real-time basis to the ship's central computing facility. The dynamic lag of the angle servos and the receiver AGC voltage are also available in digital form to enable the central computer to further refine the already precise radar outputs.

RCA, in designing to the requirements formulated by the Goddard Space Flight Center (Technical Exhibit GSFC-OIS-1, Revision B, dated 10 July 1964), determined that some design innovations were needed to expand the capabilities of the AN/FPS-16 to meet the specified requirements. The additional requirement for three radars in a short time period created the need to develop these design innovations on a production basis. Work commenced in the Moorestown Missile and Surface Radar Division with the signing of the contract (NAS 5-9720) on 3 August 1964. In addition to the three radar sets, the procurement also provided a full range of support items including technical manuals, spare parts, installation instructions, training, and field consultation services. Contract amendments have added field modification kits to the basic radar sets.

The program history is further detailed in the course of relating in this report the engineering development and system design philosophy. Section 2 affords the reader a concise system description where equipment features, performance capabilities, and the subsystems are all briefly summarized. In Section 3, the design approach to the system components, including functional descriptions and developmental history are presented. Acceptance testing is the subject of Section 4.

Section 2

SYSTEM DESCRIPTION

The shipborne C-band Radar Set AN/FPS-16(V) is designed to rapidly acquire and track high-performance targets and to provide tracking data of train angles, elevation deck angles, and range when operating in the beacon mode. This data will be combined with ship's attitude and location data to produce trajectory information in bearing and elevation with respect to a horizontal plane and range. A secondary function of the radar set is to provide tracking data when operating in the skin mode.

2.1 PHYSICAL DESCRIPTION

The antenna with its supporting pedestal are the only radar components located above deck. A solid-surface 16-foot parabolic reflector illuminated via a Cassegrainian configuration by a multimode, monopulse feed comprise the antenna. The antenna structure is supported by a two-axis (azimuth-elevation) pedestal, featuring a low-friction hydrostatic azimuth bearing, anti-backlash drive gearing, and precision hydraulic drives.

The below-deck equipment is contained in an integrated operator console and 31 rack-type cabinets. To facilitate alignment and troubleshooting, the cabinets are arranged in equipment banks so that most components of a subsystem are in the same bank of equipment. Air conditioning for each bank is supplied from the ship's central air conditioner. All operational controls are centralized at the console. The console circuits are packaged in eight modules with sloping front panels that slide forward to permit easy access. The wiring in the rear of the console is also readily accessible through four doors covering the entire rear of the console.

2.2 DESIGN FEATURES

The radar may be functionally divided into the following subsystems: transmitter, microwave components, antenna, pedestal, receivers, angle servos, range tracker, console, and digital data subsystems. Several ancillary equipments are also provided to increase the flexibility of the basic radar set.

A continuously tunable magnetron provides the C-band power to illuminate the target via the 16-foot Cassegrain antenna. The angle servos, or antenna positioning subsystems, are high torque-to-inertia electro-hydraulic servo loops stabilized with on-mount gyroscopes and the deck pitch and roll rates provided by the ship's inertial reference. The multimode feed in conjunction with the dual-polarization comparator and the polarization programmer develops conventional monopulse tracking signals which are supplied to the antenna positioning and range servos through the three-channel receiver subsystem. An all-electronic, digital ranging subsystem affords unambiguous range coverage to 32,000 nautical miles at high pulse-repetition rates with a granularity of 2 yards. The digital data subsystem provides the interface between the radar system and the ship's central computer.

In order to maximize the probability of detection and to initiate automatic tracking on the weakest target returns in the shortest possible times, the radar system is provided with a diversified complement of acquisition aids. The acquisition features include: digital detection which utilizes counting techniques to statistically evaluate target presence in one of 20 contiguous range gates; auxiliary angle tracking (auxtrack) which enables the radar to detect, acquire, and track a target in angle, independently of the range-tracker-gate position; antenna search scans and controls in association with the C-scope display which can be used as a substitute or supplement for inaccurate angle designation information; and an integrated console which provides a completely centralized location for systems operation and parameter selection.

The design features that differentiate the ASIR design from previous members of the AN/FPS-16 family are briefly described below; details are reserved for Section 3.

2.2.1 Transmitter

The design of the ASIR transmitter closely parallels the configuration of earlier AN/FPS-16 transmitters (i.e., a hard-tube modulator is used to pulse a self-excited magnetron oscillator). The tunable quarter-megawatt and the fixed-tuned one-megawatt magnetrons of previous designs were replaced with a single SFD-313 continuously-tunable C-band magnetron, capable of delivering one megawatt of peak power at a duty factor of 0.0011. In addition to providing increased tuning flexibility, the SFD-313 magnetron has a longer life expectancy and higher operational stability (lower probability of sparking and moding) than previously used tubes.

RF power delivered to the antenna is channeled through a variable attenuator (the transmitter power programmer), that controls the radiated power level. At the operator's option, the attenuation may be manually set at the console or automatically controlled by the range tracker as an inverse function of range.

2.2.2 Microwave Components

The microwave components encompass the low-loss high-power transmission path between the transmitter and the antenna feed as well as the low-level paths from the feed to the three mixer stages. Standard, field-proven, AN/FPS-16 components have been utilized throughout although a second reference channel has been added for circular polarization. A VSWR indicator is provided in the transmit channel. Electrically controlled ferrite phase shifters were inserted between the local oscillators and the mixers to compensate for phase differences resulting from switching between linear and circular polarization or switching between beacon and skin tracking.

2.2.3 Antenna and Multimode Feed

A unique and significant design feature, which sets the ASIR radar apart from any other AN/FPS-16 (including the 16-foot diameter Cassegrain-antenna version developed for use on the T-AGM-8 missile range ship), is the ultra-high efficiency, dually polarized, single aperture, mu . monopulse feed system. This superior feed is the result of years of company funded research in this area and provides an increase in gain of from 1 to 2 db over that previously obtainable from an aperture the same size. The benefits thus realized may be taken as increased sensitivity from an aperture of given size, or a decrease in antenna size, weight and inertia for a given sensitivity. These salutary performance characteristics are preserved over the full frequency band (5.4 to 5.9 Gc) of the radar without the need for tuning adjustments of any kind.

The feed radiates, receives and processes two orthogonal linear polarizations (vertical and horizontal) independently. By means of appropriate polarization control circuitry external to the feed, the system has the capability of providing any desired polarization for radiation and reception. In this system the polarizations provided are vertical transmit and receive or left-hand circular transmit with right-hand circular receive although the potential for growth to the full polarization diversity is retained.

2.2.4 Pedestal

The ASIR pedestal is a two-axis (elevation over azimuth) instrumentation mount designed to support and accurately position the 16-foot solid-surface antenna. The structure features high pointing precision, smooth low-velocity tracking, and digital data readout of position at a precision level consistent with the inherent capabilities of the mount.

The AN/FPS-16, Mod 1 pedestal with a hydrostatic azimuth bearing and anti-backlash gearing provided the basic guidelines for the ASIR design. The major design improvements to the Mod 1 pedestal include on-mount gyro stabilization, adaptations to meet the environmental requirements for shipboard operation, improved stowage, and a general redesign for increased accessibility and ease of maintenance.

2.2.5 Receivers

The receiver subsystem develops and processes the three-channel IF information to provide the range and angle-servo video signals required for three-coordinate tracking. Received energy is first processed in the antenna and microwave subsystems to produce the C-band angle-error and reference signals. These signals are fed to the mixers where they are heterodyned with either or both the skin and beacon local-oscillator outputs to produce the 30-Mc IF signals. The IF bandwidth is selectable to provide optimum signal processing for the various system pulse widths.

Substantial portions of the basic AN/FPS-16 receivers were utilized in this design. The significant differences include the replacement of the non-track channel with an acquisition channel and a redesign of the AFC functions to fulfill the ASIR system requirements.

2.2.6 Angle Servos

The angle servos are the control loops that position the pedestal turntable in the azimuth (or bearing) coordinate and the antenna reflector in the elevation coordinate. During designation and target acquisition, error signals into the control loops are supplied either through synchro inputs or digitally from the ship's central computer. Once angle tracking of the target has been established, the control loops are closed with the angle-error signals developed by the monopulse feed.

The following design features are employed in the ASIR servo equipment:

1. On-mount gyro and ship's motion velocity feed forward stabilization loops for isolation of ship's motion.

2. The ASIR servo configuration performs the same functions as the AGM-8 servo configuration but in addition performs on-mount gyro stabilization. Nine chassis required in the previous design were replaced by one stabilization amplifier chassis.

3. Stabilization amplifier uses all solid-state circuitry with printed circuit modular construction of all amplifier stages.

4. Linearized servo valves to maintain servo bandwidth over the wide speed torque range imposed by ship's motion and wind loading.

5. Hydraulic damping using spring coupled cross-line leakers.

6. Mechanical pre-loading of the bearing-axis power gear train and pivoted-type elevation-axis power gear train to essentially eliminate backlash.

7. Hydrostatic bearing for low load stiction in the bearing axis. Low stiction roller-type bearing in the elevation axis.

8. High structural stiffness and damping that enables high servo bandwidth with wide margin of stability. The high structural damping also minimizes equipment wear.

9. High performance and reliable parallel spring-piston and ball-check relief valves.

10. Simplified secant correction that is derived in parallel with scan pattern beam coordinate conversion operation.

11. Flexibility in servo position loop compensation to allow conversion to compensated Type III operation.

12. High performance, wide dynamic range gyro loop is achieved with simple, low cost, and reliable loop mechanization using a torsion bar rate gyro.

13. Voltage clamping throughout electronic circuitry to prevent saturation hangup and resulting pedestal runaway.

14. Automatic dither reduction when pedestal is moving.

15. Current feedback around the valve to compensate for valve phase shift.

16. Compensated pump on hydrostatic bearing manifold to maintain constant pressure (low stiction).

17. High supply pressure to provide high servo pressure gain and high torque (wide dynamic range). Supply pressure is well regulated to maintain servo gain and sensitivity. Accumulators are sized to enable continuous velocity operation at 75% of rated flow (speed) in 45-knot winds in both axes.

18. All demodulator circuits are essentially drift-free using transformer gated matched solid-state switching.

19. Protective fail safe brakes and automatic elevation valve centering when buffer limits are exceeded. Drive out of the buffers is automatic.

2.2.7 Range Tracker

The Advanced Digital RANge tracker (ADRAN) is an all-electronic design using an Nth-time-around tracking technique to provide continuous, unambiguous, and precise range measurements on targets out to 32,000 nautical miles. Should a future requirement arise, the ADRAN tracker can be readily expanded to cover ranges out to 256,000 nautical miles.

The basic range machine is supplemented with auxiliary angle tracking (auxtrack) which utilizes many of the range tracker components. The auxtrack feature enables the radar to quickly detect, acquire, and track a target in angle, independently of the range-tracker-gate position. The console operator can designate ADRAN to the auxtrack-determined range.

The ADRAN tracker features double-threshold detection or binary integration; leading-edge, trailing-edge or "center of gravity" tracking; find and verify processes that eliminate range ambiguities and automatic and manual phasing of the transmitter that prevents locking on beacon responses produced by other radars interrogating the common beacon.

2.2.8 Radar Console

The console is the central control point for operation of the radar system. The console in conjunction with the system switching unit provide the interface through which the radar operators can select and control the operational parameters and monitor the system performance.

Basic human engineering principles were combined with a knowledge of range operating procedures to create a control and display unit that is sufficiently flexible to permit both manual and automatic modes of target acquisition and tracking. The built-in flexibility of the console controls along with any prior knowledge of the target dynamics should materially enhance the operator's skill at detection, acquisition, and tracking of high-performance missile and satellite objects.

2.2.9 Digital Data Subsystem

The digital data subsystem links the ship's central computer with the angle encoders, the range tracker, the receiver, the angle servos, and the console. This subsystem encompasses all the elements associated with the extraction, code conversion, scale changing and display of the radar coordinate data. It also provides the analog-to-digital conversion (and vice versa) for all the signals passed between the various radar subsystems and the ship's central computer.

Two significant design improvements have been incorporated into the digital data subsystem. The Gray-to-binary conversion and the ambiguity correction functions are implemented in the present design with fewer components than required by previous designs. The scale changing and code conversion required to display the coordinate data (in decimal form) at the console are performed within the data subsystem. The central computer is relieved of these time-consuming tasks and the console displays are able to present unstabilized coordinate data even though the central computer may be unavailable.

2.3 SUMMARY OF EQUIPMENT CHARACTERISTICS AND SYSTEM PERFORMANCE PARAMETERS

The principal equipment characteristics for each subsystem are tabulated in this section. The tabulations are provided as a convenient reference; actual compliance of each subsystem with the specified requirements is discussed in Section 4, under the acceptance testing program. A summary of the system performance parameters follows the list of equipment characteristics.

2.3.1 Transmitter

Frequency range	5450 to 5825 Mc, continuously tunable
Peak power output	1 Mw
Nominal pulse widths	0.25, 0.50, 1.00 microsecond
Pulse repetition rates	
Primary (Nth-time-around tracking)	160, 640 pps
Auxiliary	142, 341, 366, 394, 467, 569, 682, 732, 853, 1024, 1280, 1364 pps

Console selection	160-, 640-, and 1024-pps rates are wired to three console pushbuttons. Three additional pulse repetition rates can be wired for console selection.
Duty Cycle	0.0011 maximum (any combination of PRF and pulse width that exceeds this value is disallowed)
Pulse Coding	Up to five 0.25-microsecond pulses per repetition period with minimum leading edge spacing of 1.0 microsecond (Pulse-to-pulse variation in any pulse group 1.0 db)
Power Programming Range	20 db minimum, either automatically controlled by the range tracker as a function of target range or manually controlled by the console operator
Built-in test equipment	Power monitor (Cabinet 104)

2.3.2 Microwave Components

VSWR	2.0:1 in the transmit channel and in each receive channel
Transmit channel power handling capability	3 Mw peak, 5 Kw average
Built-in test equipment	Noise-figure monitor VSWR indicator (for the transmit channel)

2.3.3 Antenna and Multimode Feed

Main reflector	16-foot diameter paraboloid of revolution with a f/D of approximately 0.292
Subreflector	18-inch diameter hyperboloid of revolution mounted on a quadripod structure with its focus coincident with that of the paraboloid
Operating frequency range	5400 to 5900 Mc (without any tuning adjustments)
Polarization modes	Transmit and receive linear vertical or transmit left-hand circular and receive right-hand circular (selectable from console)

Power Handling Capability	3 Mw peak, 5 kw average
Gain	46 db minimum
Beamwidth	0 .1° ± 0.04°
Reference channel and error channel side lol	ttenuated 18 db relative to the radiaon intensity at the peak of the main be (Refer to Acceptance Testing)
Error pattern depth of l	Down at least 35 db from reference pattern peak

2.3.4 Pedestal

Type of Mount	2-axis, azimuth and elevation
Rotation limits:	
Azimuth	Continuous
Elevation:	
Tracking	-10° to $+70^{\circ}$
Boresighting	-10° to 190°
Drive	Hydraulic valve-motor; two in azimuth, one in elevation
Power gear train:	
Azimuth	Dual aiding with mechanical pre-load
Elevation	Single pivoted low backlash
Main bearing:	
Azimuth	Hydrostatic
Elevation	Ball and roller
Maximum speed:	
Azimuth	800 mils/sec in winds up to 45 knots
Elevation	450 mils/sec in winds up to 45 knots
Maximum acceleration	1.3 rad/sec^2 in winds up to 45 knots (both axes)

2.3.5 Receivers

Noise figure	11 db (standard AN/FPS-16 mixer)
Dynamic range	73 db
Intermediate frequency	30 Mc
IF bandwidths	2.2 ± 0.5 Mc and 9.0 ± 1.4 Mc (selectable from console)
AFC:	Either beacon or skin
Pull-in range at IF S/N of 25 db	±12 Mc
Pull-in range at IF S/N of 6 db	±6 Mc
Beacon AFC reference	Beacon returns
Skin AFC reference	Either skin returns or transmitter sample

2.3.6 Angle Servos

Maximum tracking velocity:	
Azimuth	800 mils/sec in winds up to 45 knots 650 mils/sec in winds up to 60 knots
Elevation	450 mils/sec in winds up to 45 knots 300 mils/sec in winds up to 60 knots
Maximum tracking acceleration:	
Azimuth	1.3 rad/sec^2 in winds up to 45 knots 1.0 rad/sec^2 in winds up to 60 knots
Elevation	1.3 rad/sec^2 in winds up to 45 knots 0.6 rad/sec^2 in winds up to 60 knots
Maximum tracking bandwidth	4.5 cps without gyro stabilization, 2.5 cps with gyro stabilization
Track bandwidth selections	0.9, 2.5, 4.5 cps
Track velocity constants	250, 340, 400 sec^{-1}
Track acceleration constants	2, 16, 50 sec^{-2}

Ships motion stabilization:	
On-mount gyros	20 db isolation up to 0.2 cps
Computed velocity feed forward	14 db isolation up to 0.2 cps
Acquisition	Digital computer or analog (single 1:1 speed synchro)
Scan patterns	Circle, spiral, raster, rectangular in either digital or analog acquisition

2.3.7 Range Tracker

Measurement interval	500 yards to 32,000 nautical miles (expandable to 256,000 nautical miles)
Output data word length	25 bits
Output data granularity	1.953 yd/bit
Velocity tracking capability	20,000 yd/sec
Acceleration tracking capability	20,000 yd/sec^2
Slew rate	240,000 yd/sec
Velocity constant (Kv)	infinite (type II servo)
Acceleration constant (Ka)	2500/sec^2
Master oscillator stability	1×10^{-8} parts/day
Internal random error	3 yd RMS (S/N of 18 db)
Probability of detection (Multiple gate array)	99.9% in 30-millisecond interval with an S/N of 10 db at PRF of 640 pps and a false-alarm probability of 10^{-4} on a target moving at 20,000 yd/sec.

2.3.8 Data Subsystem

Angle encoders (azimuth and elevation)	
Type	2-speed mechanical-optical
Mechanical encoder output	5-bit Gray-code word

Optical encoder output	13-bit Gray-code word
Redundancy	LSB of the mechanical encoder and the MSB of the optical encoder are redundant
Angle resolution (granularity)	0.0488 mil/bit
Output digital data	
Readout rate	10, 20 or 40 samples/sec
Shift rate	100,000 bits/sec
Shift order	Serial, LSB first
Data form	Non-return-to-zero (NRZ) with LSBs aligned
Azimuth word	17-bit binary
Elevation word	17-bit binary
Az and El offset word	8-bit binary for Az offset; 8-bit binary for El offset
Range word	25-bit binary
Angle error and AGC word	8-bit binary for AGC voltage; 8-bit binary for Az error; 8-bit binary for El error
Identification word	10-bit word (3 bits are provided as spares) for computer program control
Input Digital data	
Range-designation word	21-bit binary
Az and El designation word	10-bit elevation error word; 1-bit for El servo gain; 10-bit azimuth error word; 1-bit for Az servo gain; 3-bits reserved for possible automatic bandwidth control
Feed forward word	10-bit elevation velocity; 10-bit azimuth velocity
C-scope word	8-bit elevation deflection; 8-bit azimuth deflection
Stabilized Az word	17-bit binary

Stabilized El word	17-bit binary
Range rate word	15-bit binary

Synchro data outputs

Azimuth (coarse)	360°/revolution
Elevation (coarse)	360°/revolution

Supplementary inputs and outputs

The Radar Data Junction Box (Cabinet 180) provides a centralized location for the radar interface with other shipboard systems. Digital data lines, video signals, synchro signals, relay contact closures, etc., are all available at the Radar Data Junction Box for external distribution. Volume 8 of the Technical Manual for Radar Set Model AN/FPS-16(V) contains a complete listing of all the available signals.

2.3.9 Summary of System Performance

2.3.9.1 Volume of Coverage

Range Coverage	Up to 32,000 nautical miles
Angle Coverage	
Elevation (with respect to the deck plane)	-10 to $+70^{\circ}$
Bearing (with respect to ship center line looking forward)	$\pm 165^{\circ}$

2.3.9.2 Target Characteristics

	Beacons on low orbiting vehicles (Type A)	Beacons on space or high orbiting vehicles (Type B)	Beacons at ranges greater than 8500 nm
Receiver sensitivity	-65 dbm	-75 dbm	-75 dbm
Antenna gain	24 db (2 db waveguide loss)	24 db (2 db waveguide loss)	15 db (0 db worse case
Transmitter peak power	57 dbm	74 dbm	2.5 Kw

	Beacons on low orbiting vehicles (Type A)	Beacons on space or high orbiting vehicles (Type B)	Beacons at ranges greater than 8500 nm
Transmitter frequency drift	5 Mc	10 Mc	±4 Mc
Range tracking requirement	850 nm	850 nm	8500 nm
Range rate	0 to 45,000 ft/sec		
Range acceleration	0 to 4,500 ft/sec^2		
Angle rate	0 to 15°/sec		
Angle acceleration	0 to 10° sec^2		

NOTE: For the radar system to auto track a target, the combined ship and target dynamics must be within the maximum velocity and acceleration capabilities of the pedestal.

2.3.9.3 Measurement Accuracies

(On targets with signal-to-noise ratio of at least 18 db, within ±1/4 beamwidth about the beam axis, and after error correction is performed in the ship's central computer.)

Angle Error*	1-σ value
Random component (above 5 cps)	0.1 mil or less
Cyclic component (between 0.01 and 5 cps)	0.1 mil or less
Systematic component (below 0.01 cps)	0.1 mil or less
Range Error**	
Random component	15 ft or less
Cyclic component	10 ft or less
Systematic component	15 ft or less

*Exclusive of all atmospheric and multipath effects
**Exclusive of beacon delay and velocity of propagation errors

2.3.9.4 Acquisition Aids

External sources of designation data	Central Data Processor, Unified S-Band System, Telemetry System, MK-51 Optical Tracker, and Acquisition Control Console (spare console pushbuttons are provided for additional sources)
Angle Acquisition Aids	
Auxiliary Angle Tracking (Auxtrack)	
Acquisition range	Either the full range of operation or within a 40-Kyd interval gate
Probability of detection	99.5% or better in 0.2 seconds on a target having a 10-db S/N as measured at the IF output.
Antenna Scans	
Circle	Circle diameter adjustable from 1 to 6 degrees.
Spiral	Diameter of spiral adjustable out to 5.5 degrees.
Raster	2.4 by 8 degrees (major axis in either Az or El coordinate).
Rectangular	0.6 by 8 degrees (major axis in either Az or El coordinate).
Offset Angle	$\pm 7.5^{\circ}$ in either axis by console joystick control.
Range Acquisition Aid	
Digital Detection with Multiple Gate Array	
Number of gates	20
Required designation accuracy	$\pm$10,000 yds
Probability of detection (for 30 millisecond interval)	99.9% with an S/N of 10 db and a false alarm probability of 10^{-4} on a target moving at 20,000 yd/sec.

2.4 SYSTEM SIGNAL FLOW

With reference to the overall system block diagram, Figure 2.4-1, the flow of the principal signals in the radar is briefly described: This discussion complements Section 3 where the subsystems are detailed. The Radar Set AN/FPS-16(V) is an automatic system capable of continuously tracking the path of high performance targets and providing precise data outputs of the target path in spherical coordinates referenced to the radar position.

2.4.1 Transmit Signal Generation

The pulsed RF energy radiated into space is initially generated in the magnetron cavity. The RF oscillations are induced in response to video pulses (singly or in coded groups) supplied from the range tracker that actuate the hard-tube modulator.

The one-megawatt peak power output of the transmitter is channeled through a variable attenuator (power programmer) to adjust the radiated power level. At the operator's option, this unit may be automatically servo-controlled, introducing attenuation as an inverse function of target range, or manually controlled.

A directional coupler enables power monitoring and a dual directional coupler in the transmit channel after the power programmer permits measurement of the voltage standing wave ratio.

2.4.2 Radiation and Reception

The transmit signal travels through waveguide, duplexer, and rotary couplers to the feedhorn assembly. Within the feedhorn assembly, the setting of the polarization programmer determines whether the radiated energy will be circularly or linearly polarized. Transmission of circularly-polarized energy is obtained by splitting the power in half and directing the two components to the feedhorn in space and phase quadrature. Linearly-polarized transmission is effected by applying full power to only the vertical channel.

The propagation system employs a Cassegrainian configuration combining high aperture-illumination efficiency with high phase efficiency to produce a minimum gain of 46 db over the entire range of operating frequencies.

In the multimode feedhorn, six modes are required for each of the two orthogonal linear polarizations for efficient monopulse operation. The TE_{10} mode and the two sidelobe suppression modes, TE_{12} and TM_{12}, are combined to produce the reference channel pattern. The E-plane difference pattern is derived from the TE_{20} mode while the H-plane difference pattern is obtained from the TE_{11}-TM_{11} mode combination.

2.4.3 Receiver

Three essentially identical receiver channels process the sum and two differences signals required for monopulse detection. Three mixers convert the C-band energy to IF signals, resulting in a radar receiver noise figure of

11 db in each channel. Two klystron local oscillators are used, one for skin and one for beacon signals. They may be energized separately or simultaneously.

An ungated channel is provided to the range tracker which is utilized for range acquisition and console range display.

AFC can be effected while tracking either beacon or skin returns. Provisions are included to maintain a constant frequency difference between the skin local oscillator and either the skin returns or samples of the transmitted signal. The AFC loop for the beacon local oscillator utilizes the beacon return as the frequency reference.

2.4.4 Angle Servos

Commutated error video, developed during automatic tracking, or synchro and digital designation data, either local or remote in origin, are converted to control signals in the azimuth and elevation servo loops. These control signals, with amplitudes and polarities dependent upon the magnitude and direction of the antenna pointing error, determine the antenna rate and rotational direction for each axis.

A combination of signals from on-mount gyros and computed values of the ship's rate of motion is used to effectively isolate the pedestal motion for that of the ship and thus stabilize the antenna beam position in inertial space. In essence, the feed-forward signals of ship motion derived from the ship's inertial system provide coarse corrections for the angle servo loops while the on-mount gyro signals act as extremely smooth vernier corrections.

2.4.5 Range Tracker

Digital and Nth-time-around-tracking techniques are combined in the range subsystem to attain an unambiguous measurement interval of 32,000 nautical miles with high pulse-repetition rates, two-yard granularity, and excellent precision. In a conventional pulse-type radar, the unambiguous range is inversely related to the PRF, severely curtailing the sampling rate at longer ranges. Extended range coverage in Radar Set AN/FPS-16(V) is achieved without reducing the repetition rate through multiple-time-around tracking. A low repetition rate (2.5 pps) serves as the time base and a relatively high one (160 or 640 pps) as the PRF.

The maximum range measurement is established by the 2.5 pps repetition rate. By dividing this time base into either 64 or 256 zones, dependent on the PRF employed, as many transmissions as zones may occur before the first pulse is received. True range is measured by locating a return within a zone (apparent or ambiguous range) and adding it to the range established by the number of zones between the return pulse and the RF transmission which caused it. Ambiguity resolution can be a two-step process called find and verify. Verification is tried immediately following target lock-on and if not successful, the system switches to find.

The find process determines the target location zone and the verify process confirms that the found zone is the correct one. In the find mode, two successive transmitter pulses are delayed 2,000 yards. Concurrently, double range gates are generated in each pulse repetition period, the second gate being displaced 2,000 yards from the first. The number of transmissions relative to the delayed ones are counted until two video pulses are detected in the delayed range gates.

The verify process is then initiated. For verification, eight transmitter pulses and the range gates in the assumed zone are delayed in a pre-determined sequence (2, 4, 6, 8, 8, 6, 4, 2 Kyd). The delayed gates are then checked for the presence of a target return. The verify process is completed if four out of eight video pulses are detected. Failure to verify causes the find process to repeat.

To avoid interference between received and transmitted pulses, since the transmitted pulse cannot be excluded by the receiver, the system introduces an alternating transmitter-pulse/range-gate delay sequence. This technique enables time separation of the transmitter pulses and target returns when the received signals are in the predetermined interference region without changing the sampling rate. A region of ± 16,000 yards about the time positions of the transmitted pulses is allowed to also exclude signals due to ground reflections.

Automatic tracking is accomplished in a type-II servo loop. Split gate techniques superimposed on the gated video and coupled with a time discriminator are used to derive range errors. The magnitude of the range error is dependent upon the time position of the target return with respect to the center of the tracking gate. The polarity of the range error is established by the relative energy levels bracketed by the split (early and late) gates. The range error is integrated, converted to a ramp voltage with a slope and polarity equivalent to the magnitude and direction of the range error, and then changed in an analog-to-digital converter to a series of error pulses. The error pulse frequency is dependent upon the slope of the ramp voltage and consequently the magnitude of the range error. These error pulses are then used to correct the range counter and re-position the track gate. Provisions are also included for either leading-edge or trailing-edge tracking of the video returns.

The range tracker also generates precise timing signals for its internal operation, as well as the system triggers. Automatic and manual sequencing of the PRF are included to eliminate interference caused by the nearly simultaneous arrival at the beacon of interrogation pulses from several radars in a tracking chain.

2.4.6 Detection and Acquisition

The digital detection scheme uses multiple adjacent search gates together with a binary quantizer and step counter system. The search range interval spans 20,000 yards and is composed of an array of 20 search gates, each having a width of 1000 yards. Generation of the search-gate sequencing voltage is accomplished by means of a 20-stage binary shift register with each stage having an associated gate and a six-stage binary counter. Ungated video is reviewed by the binary quantizer and whenever the video level exceeds the threshold of this circuit, a standardized pulse is developed. These pulses are gated into the six-stage binary counter, as they occur, corresponding to one of the acquisition gates. Target detection is based on the premise that with the proper threshold settings, the counters corresponding to the search gates containing only noise have an average noise count with a known variance, but the gate containing a target has a higher average count since the mixed signal should exceed the threshold more often than noise alone. Thus, by examining a predetermined (and adjustable) number of radar periods, target presence within a gate is ascertainable.

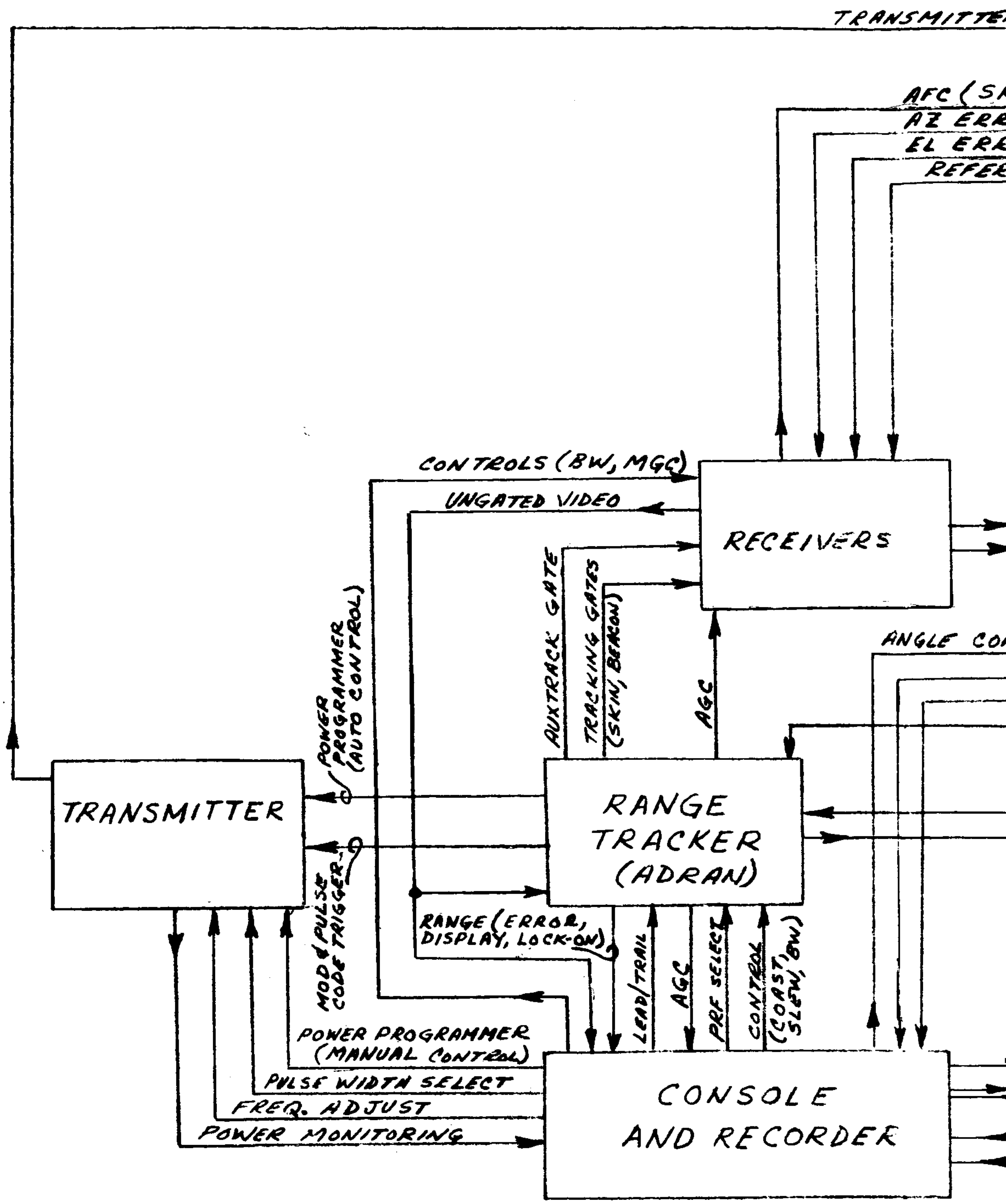
The auxiliary angle tracking (auxtrack) subsystem is a "time" tracker. A timing reference is established by detection of a target return in the ungated video, with the subsequent rate at which the auxiliary system operates determined by a PRF counter. This counter forces the periodic generation of receiver gates and other triggers required to angle track. Threshold detection techniques are employed as in the primary detection system.

Ungated video is fed to the first threshold of the auxtrack detection circuits where it is compared to a preset reference voltage level, generating a trigger when this reference is exceeded. This trigger establishes the timing reference for the PRF counter. Gated video is then fed into a second threshold. A sample gate, initiated by exceeding the first threshold, enables the second threshold for a predetermined number of returns of gated video. The second threshold reference level is adjusted so that during this interval, the threshold will be exceeded only if the signal initially selected by the first threshold has a high probability of being a target return. An output from the second threshold maintains the timing reference established by the first threshold. The repetition rate for the auxiliary tracking gates and triggers is provided by the PRF counter. Designate control circuits are included to conveniently permit the use of auxtrack data as range designate information for the range tracker.

2.4.7 Data Handling Subsystem

The data handling subsystem enables the collection, processing, display, and transmission of the radar coordinate data. This subsystem is divided into two sections: the angle encoding and the data handling sections. The angle encoders derive the angular position of the pedestal and translate this information into digital form; both azimuth and elevation shaft encoders are two-speed optical and mechanical devices. The angle encoding section includes the digital logic circuits that convert the encoder Gray-coded outputs into natural binary code and that correct ambiguities between the most significant digit of the optical encoder and the least significant digit of the mechanical encoder, since these outputs are redundant.

The data handling section enables two-way data transmission between the radar system and the ship's central computer. In addition to the digital-to-analog and analog-to-digital conversion, a minimal amount of data processing is included in this section; namely, the scale factor changing and the code conversion (binary to binary coded decimal) required for display of the radar coordinates.



TRANSMITTER
RECEIVERS
RANGE TRACKER (ADRAN)
CONSOLE AND RECORDER
CONTROLS (BW, MGC)
UNGATED VIDEO
AUXTRACK GATE
TRACKING GATES (SKIN, BEACON)
AGC
POWER PROGRAMMER (AUTO CONTROL)
MOD & PULSE CODE TRIGGER
RANGE (ERROR, DISPLAY, LOCK-ON)
LEAD/TRAIL
AGC
PRF SELECT
CONTROL (COAST, SLEW, BW)
POWER PROGRAMMER (MANUAL CONTROL)
PULSE WIDTH SELECT
FREQ. ADJUST
POWER MONITORING

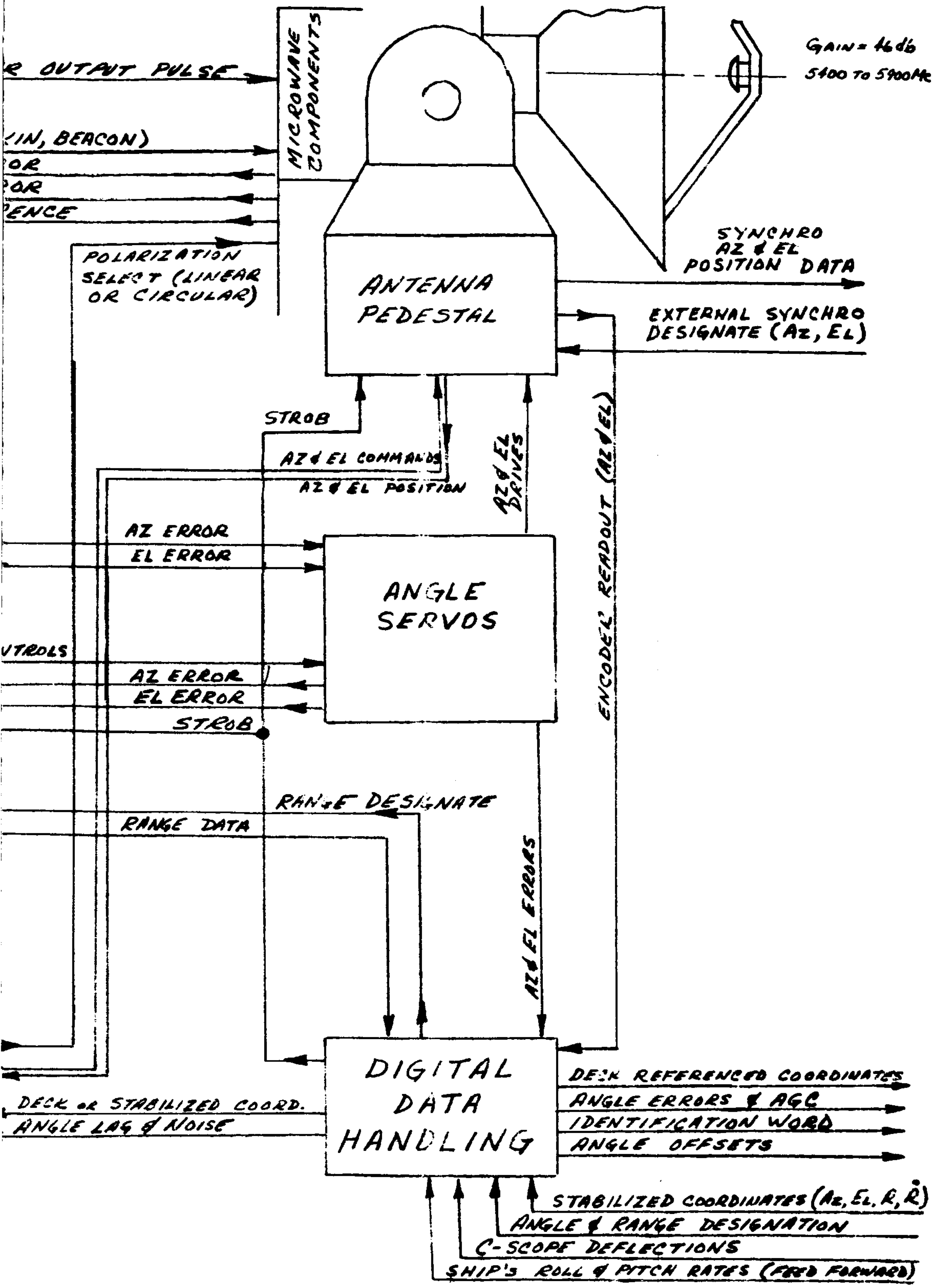


Figure 2.4-1. Simplified Block Diagram of the ASIR Radar System

2.5 SYSTEM OPERATIONAL MODES

The proper selection of the system parameters for a specific mission is dependent on many factors; for example, the mission objective, the target flight path, prior knowledge of the target characteristics, etc. The console is designed to afford the operators a maximum of parameter-selection flexibility for coping with the many diverse tracking missions that may be assigned to this range instrument.

The radar system has three primary operational modes: manual, acquisition and automatic tracking. The controls and indicators for each of the primary modes are centralized at the console. A supplementary test mode is provided for checkout of the radar system. Some of the adjustments, measurements, and calibrations required during the test mode must be performed at other than the console location.

The paragraphs that follow broadly describe the radar operational modes and indicate the type of control available to the radar operators. Detailed step-by-step operational procedures are covered in Section 3-7 of the Technical Manual for the Radar Set Model AN/FPS-16(V).

2.5.1 Manual Mode

The manual mode is selected by depressing the "Manual Mode" pushbutton on the range-acquisition panel at the radar console. This mode also is automatically selected with the application of equipment power and is intended as a standby condition for the radar from which any other mode of operation can be selected. Certain tests and calibrations will normally be made in manual mode. Within the manual mode there are three submodes: slave, matched point and local. In the local submode, the antenna and the console ordered dials are positioned by the azimuth and elevation handwheels. Because of the narrow antenna beamwidth, acquisition is generally difficult from this mode, but under limited conditions, targets may be acquired.

In the matched point submode, the antenna is again positioned by the console handwheels but the ordered dials are positioned by the selected designation source. In this mode of operation, acquisition by the operator is accomplished by positioning the antenna until the antenna positions and the ordered dials coincide. If the designated angular position is accurate, the video return will appear on the full-range A-scope display. Target acquisition is then accomplished by placing the target in the range notch and depressing the "Auto Track" pushbutton.

In the slave submode, the antenna is positioned by the selected designation source and the ordered dials are positioned by the handwheels. If the designated target position in angle is within the target beam, the target video will appear on the full-range display. Acquisition is then accomplished by placing the target in the range notch and depressing the "Auto Track" pushbutton.

The functions which are automatically selected in manual mode are:

1. Manual receiver gain control
2. Wide track gate

The following functions may be selected and/or used at operator option:

1. Automatic receiver gain control (AGC) may be selected. Manual receiver gain control (MGC) may be reselected.
2. Multiple acquisition "Gates On" may be selected for range lock on if target is in the multiple gate range (-10 Kyd to +10 Kyd).
3. Acquisition mode may be initiated by means of the "Acq" pushbutton. NOTE: No change in the designation source in the slave submode of either manual or acquisition can be made. Reselection of the designation source is possible only in local or matched point submodes.
4. The automatic mode may be selected by means of the "Auto Track" pushbutton.

In addition to the above, many other operating conditions and controls can be selected and/or adjusted from other modes. These are:

1. Selection of the radar pulse width. Three pulse widths are available: 0.25, 0.5 and 1.0 microsecond.
2. Selection of the pulse repetition frequency (PRF) 160, 640, 1024 (or the three previously wired in on the patch panel).
3. Selections of skin or beacon tracking. An adjustable delay line is located on the range test panel in Cabinet 123 to adjust for the beacon delay so that the range data output is correct for both beacon and skin targets. This delay line also allows switching from skin to beacon track (or vice versa) without loss of track.
4. Selection of skin-beacon presentation allows the operator to monitor the beacon signal return when skin tracking or to monitor the skin signal return when beacon tracking.
5. The non-tracking receiver gain control may be selected and used. This feature is included to enable the operator to investigate the character of signals weaker than that which is being tracked. The information is presented to the operator by superimposing it on the range indicator scope.
6. Transmitter radiation may be turned on or off. A radiation ready indicator is provided to show when radiation can be turned on.

7. Manual or automatic transmitter power output may be selected. The power programmer controls the transmitter output level over approximately 26 db. This feature is included to prevent beacon receiver saturation at short ranges. It also aids the dynamic range characteristics of the radar receiver for skin tracking. A knob is provided for manual operation. In automatic operation, the level of radiation is controlled by the range of the target. A meter indicates percent relative power.

8. Manual (MFC) or automatic (AFC) frequency control may be selected for both skin and beacon receiver local oscillators. For MFC, control knobs are available on the console. A meter is provided to enable monitoring of the frequency performance of the beacon transmitter targets and to facilitate radar receiver local oscillator adjustment. During skin tracking, AFC action is possible when sampling either the transmitted pulse or the received signal. This is selectable when depressing either the skin "AFC Xmitter" or "Skin AFC Rcvr" pushbutton. An AFC Deactivate lamp shows when AFC action from a received signal is not possible.

9. One of two receiver bandwidths is automatically selected upon selection of pulse width. However, if the operator wishes to compromise between resolution and signal-to-noise ratio, separate receiver bandwidth controls are available.

10. The mixer diode currents may be selected and monitored by the use of the "Crystal Current Select" pushbuttons and crystal current/AGC meter.

11. Important wave forms are monitored by means of a scope. Selection of transmitter RF pulse, gated video, range error, elevation error, and azimuth error is accomplished by depressing the desired pushbutton.

12. Controls are available for motion picture camera and Versatel lens control.

13. A magnetron current meter is provided on the console.

14. Test-operate selection is available. Selection of "Test" allows switching the various test conditions into the circuits of the equipment. These will be described later for the test mode. Selection of "Operate" disallows any test condition with the exception of test conditions in the data equipment. The operator can thereby quickly and reliably prevent any test conditions from interfering with the tracking or acquisition operation.

15. Repeater dials display coarse and fine coordinate position information for azimuth and elevation. Repeater dials also show in either deck coordinate or stabilized antenna position and antenna ordered position. A ship's heading repeater is also provided. Selection of either "Deck Angle" or "Stabilized" is made via pushbuttons.

16. Numerical indicators display coordinate information for azimuth, range, elevation and range rate in decimal form. The angle display can have either deck or true angle references. This is selected by pushbutton.

17. An overload bypass on-off pushbutton arrangement is available. The equipment incorporates protective devices for various components. Selection of "Overload Bypass On" disallows the protection of these relatively inexpensive components to prevent the equipment from being disabled and thereby preserves the collection of valuable data.

18. A wavemeter and associated crystal current meter are provided to determine the local oscillator frequency.

19. Control of the paramps (when incorporated) is provided through three pushbuttons. These are as follows: "Off", "Standby", and "Operate".

20. Indicators are provided to show when bearing, elevation and ship's heading stabilization reference are on.

21. Indicators are provided to show which stabilization source the computer has selected.

2.5.2 Acquisition Mode

The acquisition mode is the operating condition of the radar which initiates and enables acquisition of a target. The ASIR radar provides for operator selections and control to accommodate the various conditions which will be encountered. The acquisition conditions for which operation has been provided are as follows:

1. 3-coordinate digital designation

2. 2-coordinate synchro designation and digital range designate

3. 2-coordinate digital designation (azimuth and elevation)

4. 2-coordinate synchro designation (azimuth and elevation) and manual range acquisition.

Within the acquisition mode there are three submodes: slave, matched point and local. The slave submode is automatically selected when the "Acq" mode pushbutton is depressed. Selection of matched point or local can be made.

If the upper (i.e., green) portion of the computer pushbutton under radar designation source is illuminated, a three-coordinate digital designation source is available from the computer. Depressing this pushbutton and then the "Acq" mode pushbutton enables the radar to accept three-coordinate digital designations. The designation data must be accurate enough to place the antenna within $\pm 1/2^{\circ}$ in azimuth and elevation and $\pm 10{,}000$ yd in range. With three-coordinate data, the radar automatically positions its coordinates to the target, then multiple gates are initiated. When the selected number of returns have occurred, the radar locks on the target (switches to automatic mode) and tracks the target. The following are automatically selected:

1. 3-coordinate digital designate

2. AGC - preset acquisition MGC

3. Acquisition servo bandwidths

4. Acquisition gate width

5. Multiple acquisition gates

6. Slave

The following may be selected and/or used at operator option:

1. Circle Scan - If the automatic acquisition and lock on does not take place and the operator decides that angle designation is in error, he may select one of the following scans: circle, spiral, rectangular, or raster. The major scan axis for rectangular or raster can be selected to be either in the horizontal or vertical plane. If in a scan, the signal is received from the target and it is within the multiple-acquisition-gate range, the radar will automatically lock on and track the target. If the target is not within the multiple-acquisition-gate region, the acquisition scope operator performs the following steps:

   (a) When target return appears on the scope, the stop-scan foot switch may be depressed by the operator.

   (b) The joystick is activated by depressing the button on the top of the joystick.

   (c) The joystick is used to steer the spot (now at the center of the scope) to the target video return location that was shown on the face of the tube. When this point occurs, the spot will brighten and the target will appear on the A-scope presentation.

   (d) The range operator may then place the range notch under the target by depressing "Range Slide Lever" under range designate select, the red button on the end of the range slide lever and then operating the range "Gate Manual Adjust" control. When the target is within the multiple-acquisition-gate zone the radar will lock-on and track the target.

2. MGC (AGC may be reselected) - For acquisition, the receiver gain is preset to keep the receiver noise output amplitude level optimum. Under certain conditions the operator may wish a higher or lower receiver gain.

3. Range Aiding - If the operator observes that range designation is in error (does not place the target within the multiple-acquisition-gate region), he may then aid the system by depressing the range-override foot switch and move the range notch to the target by the use of the "Range Gate Manual Adjust" lever. Release of the foot switch will result in multi-gate lock on and automatic tracking.

4. Automatic Mode - The mode may be selected by depressing the "Auto Track" pushbutton. If a target is within the range notch, automatic tracking will result.

5. Manual Mode - This mode may be selected by depressing the "Manual" pushbutton.

6. Acquisition Mode - This mode may be reselected. If false lock-on occurs due to interfering signals or the target designation is disconnected due to aiding operation, the operator may revert back to original designation.

If the upper portion of any of the designation sources is illuminated and is selected prior to depressing "Acq" mode, the radar can be designated in azimuth and elevation data in synchro form. When the "Acq" mode pushbutton is depressed, the radar will orient to the designated coordinate. The ordered dials will be positioned by the console handwheels. All functions and selection are available in this mode that were available in the three-coordinate digital designation mode.

If it is known prior to depressing ACQ mode that the designation source does not have range information or that it is inaccurate, either "Range Slide" lever or "Preset Range Insert" pushbutton under range designate select may be depressed.

If "Range Slide" lever is selected, the acquisition process is the same as with three-coordinate designations with the following exceptions:

1. Movement of the range notch is controlled by the "Range Gate Manual Adjust" control.

2. Lock on is accomplished by depressing "Multiple Acq Gate On" and "Auto Track" or just "Auto Track".

If "Preset Range Insert" is selected, the acquisition process is the same as with three-coordinate designation with the following exceptions:

1. The range notch is designated to the range set by switches located on the Cabinet 123A1 test panel.

2. "Acq Velocity On" may be selected. When selected, the range notch will move at the rate shown on "Range Rate Counter". The acquisition Range Gate velocity can be varied by the knob under counter in either the ingoing or outgoing direction.

3. When the target appears in the multiple-acquisition-gate zone, (if "Multiple Acq Gate On" has been selected), automatic tracking will occur.

If the match-point submode of acquisition is selected, the pedestal will be positioned by the console handwheels and the ordered dials will be positioned by the selected external designation source. Acquisition then occurs when the operator positions the handwheels so that the antenna position and the ordered dial have the same readings. All controls and functions that were available under the slave submode are now available under the match-point submode.

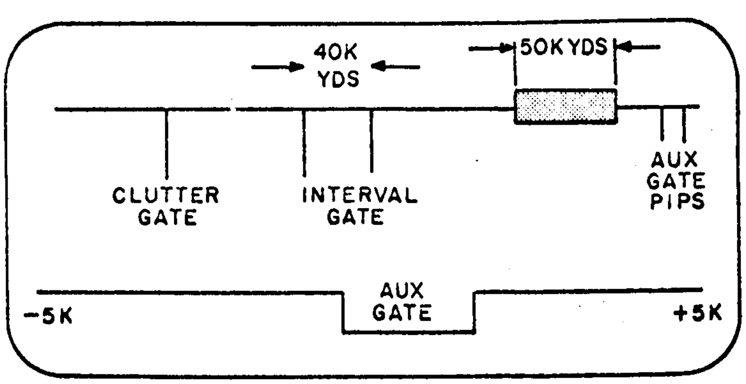
If the local submode of acquisition is selected, the pedestal and the ordered dials will be positioned by the console handwheels. In this submode it is assumed that the operator has some prior knowledge of the target position. All controls and functions that were available under the slave submode are now available under the local submode.

2.5.3 Auxiliary Angle Tracking

In any acquisition submode when the range designation is not known or is inaccurate, the auxiliary tracking equipment can be used. This function is energized or de-energized by the "Disable" or the "Operate" pushbutton under auxiliary tracking control.

Auxiliary tracking is possible in three possible conditions. In the first condition auxiliary tracking is tracking the target and controlling the antenna servo systems. In this case "Auxiliary Angle Gating" is depressed. In the second condition, auxiliary tracking is tracking the same target that the main radar range system is tracking but the antenna pedestal servos are controlled by the main radar range system. This condition is established by depressing "Normal Angle Gating". In the third condition, the two range tracking systems are tracking different targets which are both in the beam. This condition is established by depressing "Dual Tracking Gate".

The auxiliary tracking display is shown below;



The "Clutter Gate Adjust" control is used to eliminate possible lock on in a region of ground clutter in any zone other than zone 1. The region that is eliminated starts at the transmitter phase (main bang) and ends at downward clutter gate mark.

The "Interval Gate Adjust" control is used to select the region that lock-on is desired. This region is shown by two downward marks.

Three modes of operation are available in auxiliary tracking:

1. Aided - In aided operation automatic target detection is disabled. This mode is considered an auxtrack manual mode. In order to achieve manual lock-on in this mode, the "Position Gate" and "Aux Track Gate Manual Adjust" controls are operated. The location of the receiver gate is shown by two narrowly-spaced negative marks. The video, five thousand yards either side of the receiver gate, is shown on the lower auxtrack trace.

2. Interval gate - In the interval mode, automatic lock-on is allowed only within the interval gate region. This region is identified on the upper auxtrack display by the two negative pips separated by forty-thousand yards.

3. Full Range - In this mode automatic lock-on is possible in the region from the clutter gate to the end of the display.

In any of the auxiliary tracking modes, "Coast" can be selected as an aid in avoiding false tracking on interfering signals. In coast, the three coordinates continue to move at their rates of motion existing when "Coast" was selected.

2.5.4 Automatic Mode

The automatic mode is that condition that permits automatic tracking of a target although the radar can be in this mode and not tracking a target. In the automatic mode, the radar can track a target and meet all the tracking performance requirements. The following are automatically selected:

1. AGC

2. Track servo bandwidths

3. Track (narrow) gate

The following may be selected and/or used at operator option:

1. MGC (AGC may be reselected) - In automatic mode the AGC circuits automatically adjust the receiver gain to an optimum for the signal level. The operator may use MGC (manual gain control) if desired.

2. Servo bandwidth controls - These controls determine the bandwidths of the azimuth, elevation and range servo system. The operator can adjust the controls as desired in accordance with target condition. The meters display servo coordinate error in either filtered or unfiltered form as selected by the "Meter Data" pushbutton. They are provided as an operator aid for servo bandwidth control.

   Pushbutton selection of either Manual or Automatic range servo bandwidth is available.

3. The radar sends to the computer tracking errors in digital form. These errors can be used for data corrections. Controls are provided for adjusting the bandwidth of the error corrections in both azimuth and elevation. A pushbutton is provided to send "Data Corrector On Off" commands to the computer.

4. Coast - Coast is effective when the "Coast" pushbutton is depressed. The radar is returned to automatic mode when the pushbutton is released. This feature is provided as an aid in avoiding false tracking on interfering signals. In coast, the three radar coordinates continue to move at their rates of motion existing when coast was selected.

5. Leading-edge or trailing-edge tracking in the incoming or outgoing direction is available when selected by appropriate pushbuttons.

6. When ambiguous tracking PRF's (160 or 640) are selected, the radar must determine the correct range of the target. This process, called find and verify, is started automatically at range lock-on. If it is desired to prevent this process from occurring, "Find Override" is depressed. If at another time the operator wishes to initiate this process, the "Find" pushbutton is depressed. Indicator/pushbutton "Unverified/Verified" is used to show the status of the range data. If the verify circuitry has failed to verify the range of the target, the unverified (red) indicator lamp is illuminated. The verify (green) indicator illuminates momentarily when the pushbutton is depressed and indicates that the verify process has been initiated.

7. Transmitter Phasing - To eliminate "beacon stealing" when two or more radars are interrogating the same beacon target, "Automatic" and "Manual" transmitter phasing controls are provided. The "±32 Kyd" pushbuttons allow the operator to shift the transmitter phasing plus or minus 32 Kyd. The manual "ID" pushbutton allows the operator to determine that the beacon return being tracked is being interrogated by this radar. This is indicated by observing two beacon returns separated by 48 to 56 thousand yards, the first of which is in the tracking gate. Automatic phasing of the transmitter is accomplished by depressing "Automatic Xmtr Phasing On". The "Auto Xmtr Phasing Threshold" is provided for sensitivity adjustment of the automatic phasing circuits.

8. Data Valid - A pushbutton is provided to enable the operator to signal the computer that tracking is of sufficient quality. As a result of a contract change order, a console indicator was added to show the validity of the computer-supplied angle-designation data.

9. "Gyro In/Out" and "Feed Forward In/Out" - Provision is made for controlling the two methods of isolating ship's motion from the error channels. Depressing "Gyro In" pushbutton enables the on-mount gyros. Depressing "Feed Forward On" enables the ship's gyro input.

2.5.5 Test Mode

The test mode is the condition which permits certain test and calibration operations. Test mode is selected by depressing the "Test" pushbutton; the test mode is cancelled by depressing the "Operate" pushbutton.

The test conditions which are available in the test mode are as follows:

1. Boresight Tower - The boresight tower is used with radar for the important function of antenna axis collimation, alignment and check. The boresight tower serves as a signal source to simulate a target, and contains telescope target boards, radiating horns, and a signal generator which can be synchronized with the radar's timing and other components. In addition to antenna axis collimation, the boresight tower is very useful for test and calibration of many other areas of the radar. Arrangements have been provided to enable the operator to select "Boresight Tower." With this selection, the radar antenna axis will be automatically positioned to the boresight tower radiating horn. The adjustment of dials (attached to synchros) located in Cabinet 103 determine the position of the antenna for the boresight tower.

   In the boresight tower test conditions, the following are automatically selected:

   (a) Range manual position control

   (b) Slew servo bandwidth in azimuth and elevation, and manual servo bandwidth in range

   (c) Wide range gate

   (d) Position of boresight tower radiating horn in azimuth and elevation

   (e) MGC (receiver manual gain control)

   (f) Azimuth and elevation handwheels speeds are changed from 1:1 to 16:1

The following may be selected and/or used at operator option:

(a) Those 23 operating conditions and controls not strictly confined to the Manual Mode (as described in the discussion on Manual Mode in this section) are also available.

(b) Range manual position by means of the "Range Gate Manual Adjust" lever.

(c) AGC (MGC may be reselected).

(d) Multiple acquisition gates and lock-on by depressing and releasing the range foot switch.

(e) Circle, spiral, raster, and rectangular scan may be initiated by selecting appropriate pushbutton. Automatic lock-on will occur if the range foot switch is released and if the signal is within the multiple-gate region.

(f) The automatic mode may be selected by depressing (and releasing) the "Auto Track" pushbutton.

(g) Slow and fast slew in azimuth and elevation.

2. RF Head - With selection of "RF Head", the radar will automatically position the radar pedestal to the setting of the synchro dials in Cabinet 103. This may be set up so that a pedestal position which is convenient for access to the RF head results. This facility can also be used to position the pedestal to some fixed target (corner reflector or other for testing and or calibrating the radar). All the conditions and operator operations described under boresight tower test modes are available.

3. Dish - The adjustment of the synchro dial in Cabinet 103 determines the position for Dish. This can be set up so that depressing the "Dish" pushbutton will position the antenna for convenient access to the components of the antenna assembly for boresight adjustment. All other conditions are the same as RF head test mode.

4. Noise Figure - Facilities for measuring the noise figure of each complete receiver channel (reference, azimuth, and elevation) are built into the radar. Noise figure is measured by using the controls on the noise figure and power monitor chassis in Cabinet 104.

Section 3

SUBSYSTEM DESIGNS

The radar subsystem designs are the implementation of the performance requirements cited in Specification GSFC-OIS-1, Revision B, dated July 10, 1964. To fulfill the specified requirements and to ensure early equipment availability, many of the performance-proven components of previous AN/FPS-16 designs were used as "off-the-shelf" items. Where existing designs would not satisfactorily meet the performance requirements, they were used as the basis for new equipment developments.

The subsystem discussions that follow concentrate primarily on those areas where most of the development effort was expended. Functional descriptions are included only to the degree necessary to afford a clear understanding of the design approach, but this information is available in detail in the Technical Manual for Radar Set Model AN/FPS-16(V) (Systems 47, 48 and 49). Functional block diagrams of each subsystem are included that supplement the system block diagram and the equipment characteristics summary presented in Section 2, System Description.

3.1 TRANSMITTER

A simplified block diagram of the ASIR transmitter is shown in Figure 3.1-1. The transmitter is required to generate C-band RF pulses meeting the specified requirements. These pulses are generated on a one-to-one basis in response to triggers from the range tracker or coded-pulse groups from the beacon encoder. The pulse generating and amplifying equipment are located in one cabinet and the magnetron, microwave circuitry (including the power programmer), and pulser high voltage power supply are located in a second cabinet.

To meet the ASIR requirement, the AN/FPS-16 Radar Transmitter, a thoroughly proven equipment for this type of service, was simplified and improved. The tunable quarter-megawatt and the fixed-tuned one-megawatt magnetrons used in previous designs were replaced with the SFD-313 one-megawatt tube which tunes across the same frequency band as the former quarter-megawatt tube.

Improved performance results because the SFD-313 tube is a coaxial type magnetron, with characteristics excelling either of the two magnetrons formerly used. The new magnetron is almost completely spark-free, which results in smoother radar data. This freedom from sparking should materially improve the magnetron's life expectancy.

The principal design problem encountered in the substitution of magnetrons relates to magnetron voltage rise time requirements. The coaxial-type magnetron takes longer to get started, hence, the voltage applied to the cathode must rise at a slower rate than in the existing transmitter design. This was achieved by insertion of a parallel LRC shaping network in series

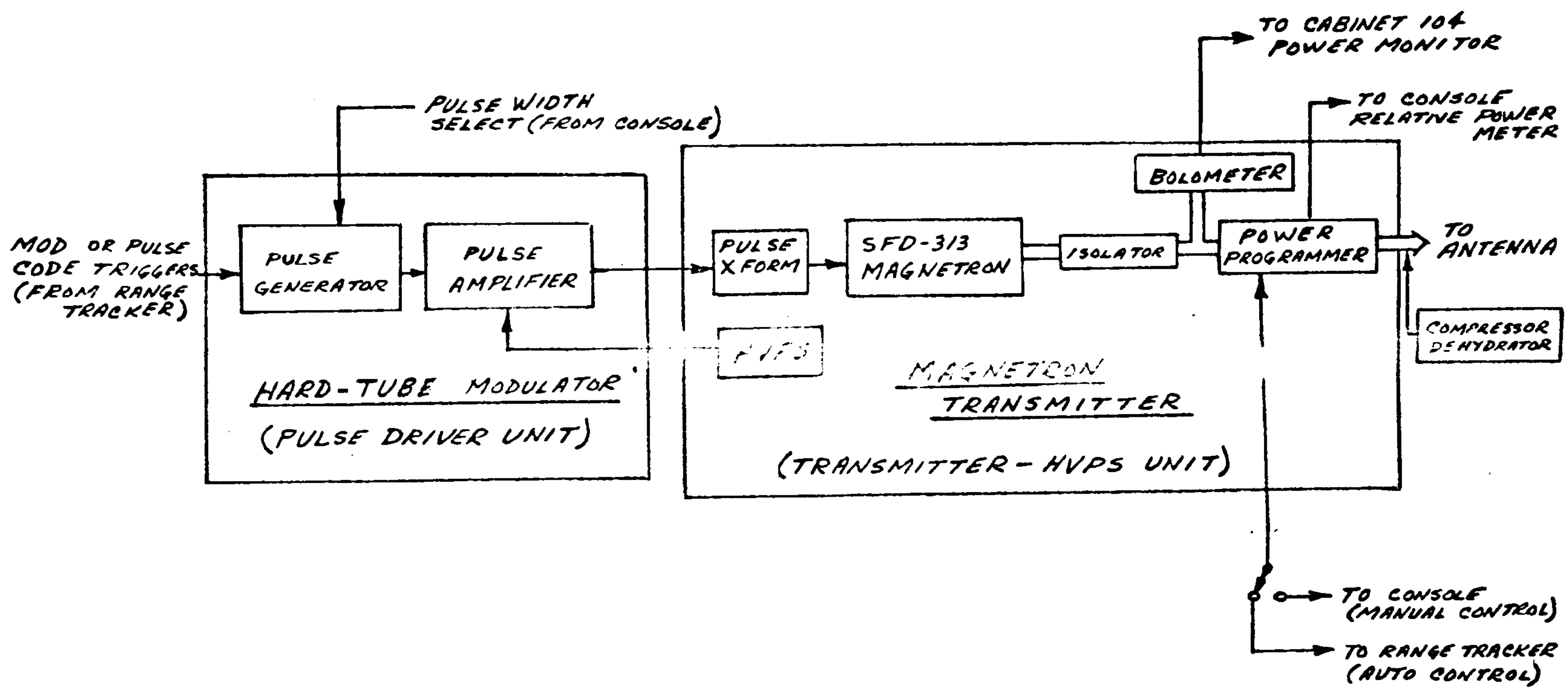


Figure 3.1-1. Block Diagram of the ASIR Transmitter

with the ground return of the magnetron pulse transformer. With this change, very stable magnetron performance was achieved.

Except for the improved magnetron, the transmitter components and circuitry are essentially identical to those used in previous AN/FPS-16 systems.

3.2 MICROWAVE COMPONENTS

The design approach for the microwave components was to provide highly reliable, time tested components of the standard AN/FPS-16 with the necessary additional items to meet the requirements of the ASIR system. Figure 3.2-1 is a functional block diagram of the microwave components. The additional features include a circular reference channel, a phase control unit, VSWR monitoring, and provisions for future addition of parametric amplifiers.

The addition of the circular reference channel was accomplished with a minimum of modification to the existing RF-head design. A suitable three-position waveguide switch was selected which inserts either the reference linear return, reference circular return, or noise generator input into the reference mixer. This method was chosen over two two-position switches to minimize the difficulty of line length equalization.

To be able to compensate for phase differences when switching between linear and circular polarization, a phase shifter control was added in the azimuth, elevation, and reference local oscillator lines. The phase shifter is a reciprocal ferrite device which can provide phase shifts of up to 60° by interaction of the RF magnetic field with a DC control field. The addition of the phase shifters, due to their insertion loss, required a higher-powered local oscillator. The tube now used is the TK 108 replacing the TK 80.

The noise-figure monitor of the standard AN/FPS-16 was retained and modified to permit the measurement of the noise level with parametric amplifiers installed. In addition, the method of calibration was changed to give a more accurate measurement over the lower range.

The VSWR measurement system which is installed between the transmitter and the pedestal derives two signals from the transmission line by a dual directional coupler. The two signals are fed to a switch, the incident power being fed through a variable attenuator. The output of the switch connects to the power bridge through a thermistor. The switch can select either a termination, the incident power, or the reflected power. These measurements can be converted to VSWR with a calibration chart.

The resultant design is a system compatible with the ASIR requirements that makes maximum utilization of the field proven AN/FPS-16 microwave components.

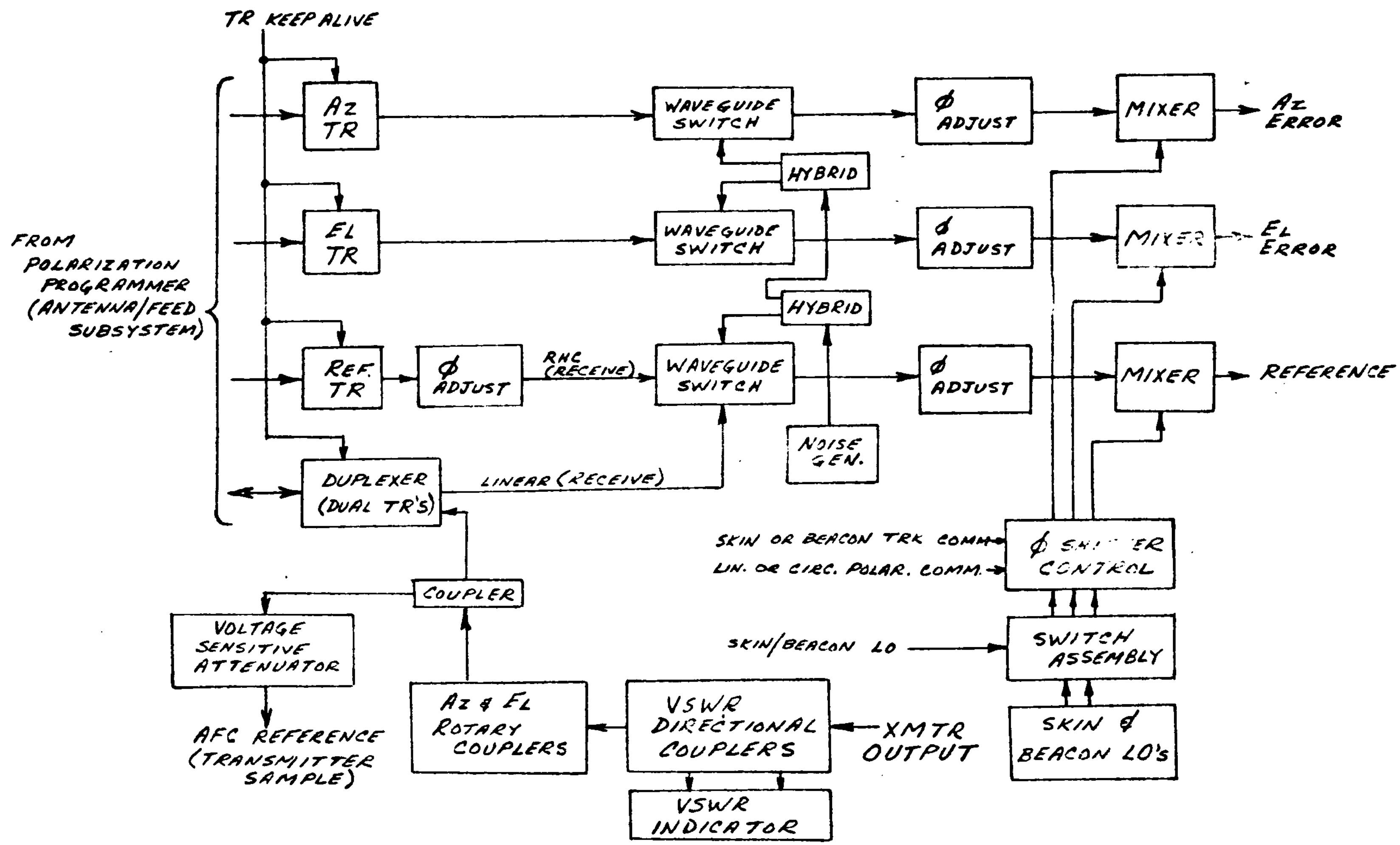


Figure 3.2-1. Functional Block Diagram of the Microwave Components

3.3 ANTENNA AND MULTIMODE FEED

The antenna supplied with this radar is a Cassegrain design; the principal antenna dimensions are shown in Figure 3.3-1. The main paraboloidal reflector is 16 feet in diameter with a focal length of 56 inches ($f/D \approx 0.292$). The reflector consists of a substructure formed by a hub module, twelve cast aluminum radial trusses, shear panels and torsion braces. Twelve solid-surfaced aluminum honeycomb reflector panels are mounted directly to the substructure.

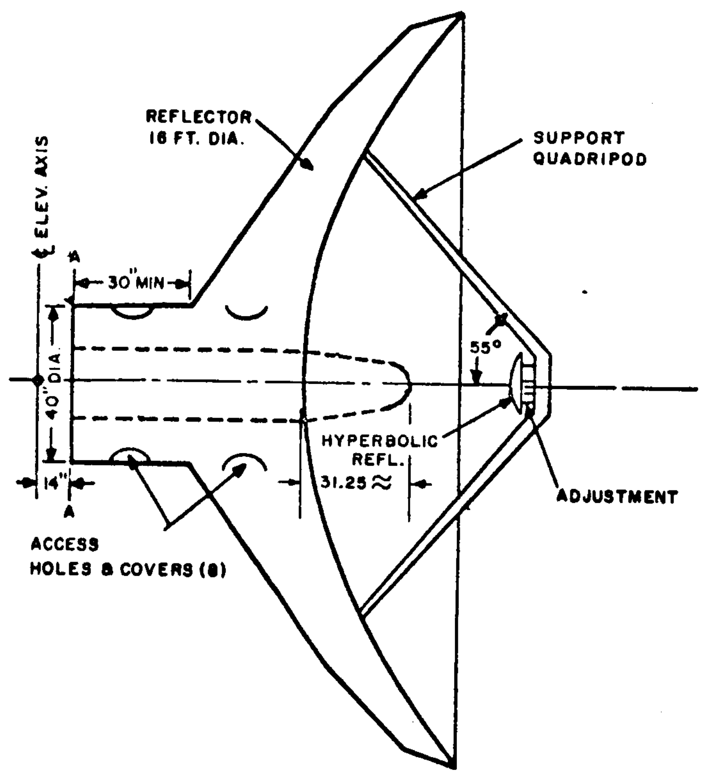


Figure 3.3-1. Principal Dimensions of the Cassegrain Antenna

The hyperboloidal subreflector is 18 inches in diameter with a distance between foci of 31.56 inches. This unit is supported by a quadripod structure which bolts directly to the primary reflector structure. The subreflector mounting and adjustment interface is located at the apex of the frame and allows for lateral (boresighting) motion of ± 1 inch, and axial (focusing) motion of 0 to -2 inches. These are non-interacting screw type adjustments with a sensitivity of approximately 0.03 inch per turn.

The multimode feed and dually polarized comparators are supported and protected within a rigid, lightweight, truncated-conical structure protruding from the paraboloidal vertex. The radiating aperture of the feed is protected from the environmental elements by a low-loss radome of polyurethane foam which attaches to the support cone. This entire assembly is adjustable laterally and tiltable for vernier boresighting.

3.3.1 Reflector Surface

The reflector surface is solid-aluminum skin and is held to a manufacturing tolerance of ± 0.030 inch from the best-fit paraboloidal contour when measured in the zenith position. A tolerance of ± 0.090 inch (i.e., the three-sigma error limit) is maintained under the worst case conditions of manufacturing tolerance, wind loading, thermal stress, acceleration and all other deflection producing effects.

The sub-reflector is a machined aluminum surface.

3.3.2 Multimode Feed

The feed subsystem may be considered as being composed of four distinct component assemblies: the feed horn, the mode generating throat, the monopulse comparator, and the polarization control circuits.

The feed horn is a one piece electroformed component which transforms the square cross section of the mode generating throat to a circular cross section at the aperture.

The mode generating throat is a machined assembly with tolerances of 0.001 to 0.002 inch which creates the required higher order modes for efficient reference pattern performance and through which the required difference pattern modes propagate freely. This unit provides a controlled impedance match to the comparator assembly and to the feed horn.

The dual-polarization comparator is a dip-brazed aluminum assembly consisting of eight waveguide hybrid junctions, four dual-mode transitions (which couple two orthogonal polarizations into a common waveguide), and four pressure windows. This unit is in effect two separate monopulse comparators, one for vertically polarized signals and the other for horizontally polarized signals (see Figure 3.3-2). The hybrid circuit configuration for each polarization is therefore simply that of the standard four-horn feed. At the feed end of the comparator, pressure windows are installed before final phase trimming is performed. There are six output channels from the comparator: Vertical Reference, Horizontal Reference, Vertical Azimuth Error, Horizontal Azimuth Error, Vertical Elevation Error, and Horizontal Elevation Error Channels. These signals are independently derived for each polarization and

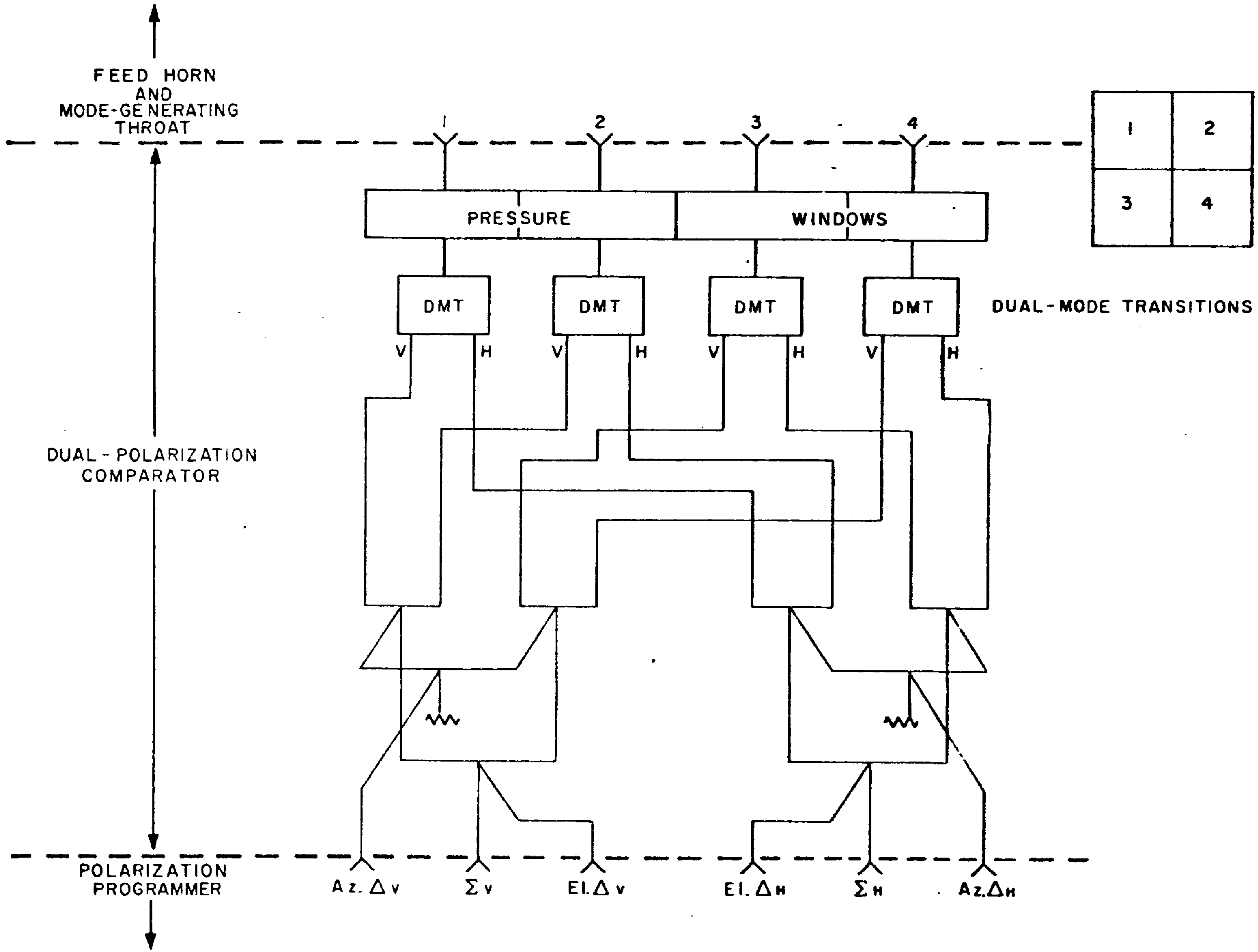


Figure 3.3-2. Schematic Representation of the Dual-Polarization Monopulse Comparator

do not interact. The action of the comparator is to set up the proper amplitude and phase relationships between the four adjacent channels to properly excite the mode generating throat of the feed to produce the monopulse sum and difference patterns.

The polarization control circuits consist of three solenoid operated double-pole, double-throw waveguide reversing switches and three 90° sidewall hybrid couplers (one each per channel). The operation of these circuits are quite straightforward. When linear polarization is selected, only the vertically polarized comparator terminals are connected to the transmitter and receivers. When circular polarization is selected, power is divided equally between (or received equally from) the vertically and horizontally polarized terminals of the comparator; the required power division and 90° phase shift being introduced by the sidewall hybrid which is switched in and out.

The theory of operation of the multimode feed may be summarized as follows. The radiation pattern characteristics of a horn depend upon the mode distributions present at its aperture. By the excitation of the proper combinations of modes of appropriate amplitude and phase, sidelobes in the primary feed pattern may be substantially reduced, and the E- and H-plane beamwidths may be equalized. These effects act to reduce the amount of RF energy lost in spillover and to increase the efficiency of a Cassegrain antenna properly designed to accept this feed.

A total of six modes are required for each of the two orthogonal linear polarizations for high efficiency monopulse operation. Of these six modes, four are generated by the outputs obtained by exciting the various terminals of the comparator. These are the TE_{10}, TE_{20}, TE_{11} and TM_{11} modes. The sidelobe suppression modes TE_{12} and TM_{12} are generated by employing a step in the feed dimensions. The magnitude and location of the step controls the amplitude and phase of the modes in the aperture. In this design, the optimum ratio has been determined to be 80% of the energy in the TE_{10} mode and 20% of the energy in the TE_{12}-TM_{12} mode combination for maximum reference channel efficiency. The H-plane difference pattern is produced by the TE_{20} mode while the E-plane difference pattern is produced by the TE_{11}-TM_{11} mode combination.

Based on measured primary feed patterns, the spillover efficiency is 83.5%. The corresponding aperture illumination efficiency is over 92%. With a phase efficiency of 97% and under 6% total aperture blockage, the computed antenna gain is 46.6 db minimum over the frequency band. Acceptance test measurements have verified the fact that the antenna gain is greater than the specified level of 46 db over the entire frequency range of the radar.

The originally proposed feed had a square aperture. During the final development of this equipment, it was found to be both mechanically and electrically desirable to change this to a circular aperture. The squareness of the horn throat is critical in this design and it is much more accurately maintained when the cross section is symmetrically transformed to a circle than when it remains square during the flaring up to the final aperture dimension.

Electrically this was found to lower the primary pattern sidelobes by approximately an additional 2 db with a slight increase in spillover efficiency over the square-mouthed horn. The final design dimensions of the antenna/feed geometry are shown in Figure 3.3-3.

3.4 PEDESTAL

The pedestal designed for this shipboard application is a two-axis configuration with elevation over azimuth (or bearing). The mount is designed to furnish accurate position data under the full range of environmental conditions imposed by the specification. The pedestal supports and rotates a 16-foot diameter Cassegrain antenna with its associated feed and subreflector. The principal parts of the antenna pedestal are broadly categorized as:

1. Pedestal base
2. Azimuth turntable
3. Elevation assembly
4. Primary and secondary reflector and associated feed (see Section 3.3).

3.4.1 Pedestal Base

The pedestal base is a heavy steel weldment that supports the azimuth axis hydrostatic bearing at its top and in turn interfaces with the ship's support tower. It is triangular in horizontal cross section. The base is designed for rigidity and thermal compatibility with the remainder of the equipment. The azimuth axis slip ring assembly, waveguide rotary joint and digital encoder chassis are housed inside the base. The azimuth stowing lock holes for the stow pins are drilled in the azimuth bull gear.

The azimuth slip ring assembly is capable of transferring video and IF signals, and AC and DC power. Spare slip rings are available for future expansion.

The azimuth data gear box is located in the base of the pedestal along the azimuth axis. The gear box shafts are coupled to the synchro and encoder shafts.

A hydrostatic bearing is used in the azimuth axis. The hydrostatic bearing has excellent stiffness characteristics with extremely low stiction torque and a high degree of reliability.

3.4.2 Azimuth Turntable

The turntable is a rigid steel plate weldment which is fixed to the inner race of the hydrostatic bearing and thus the turntable rotates about the azimuth axis. Integral with the turntable are two uprights which support

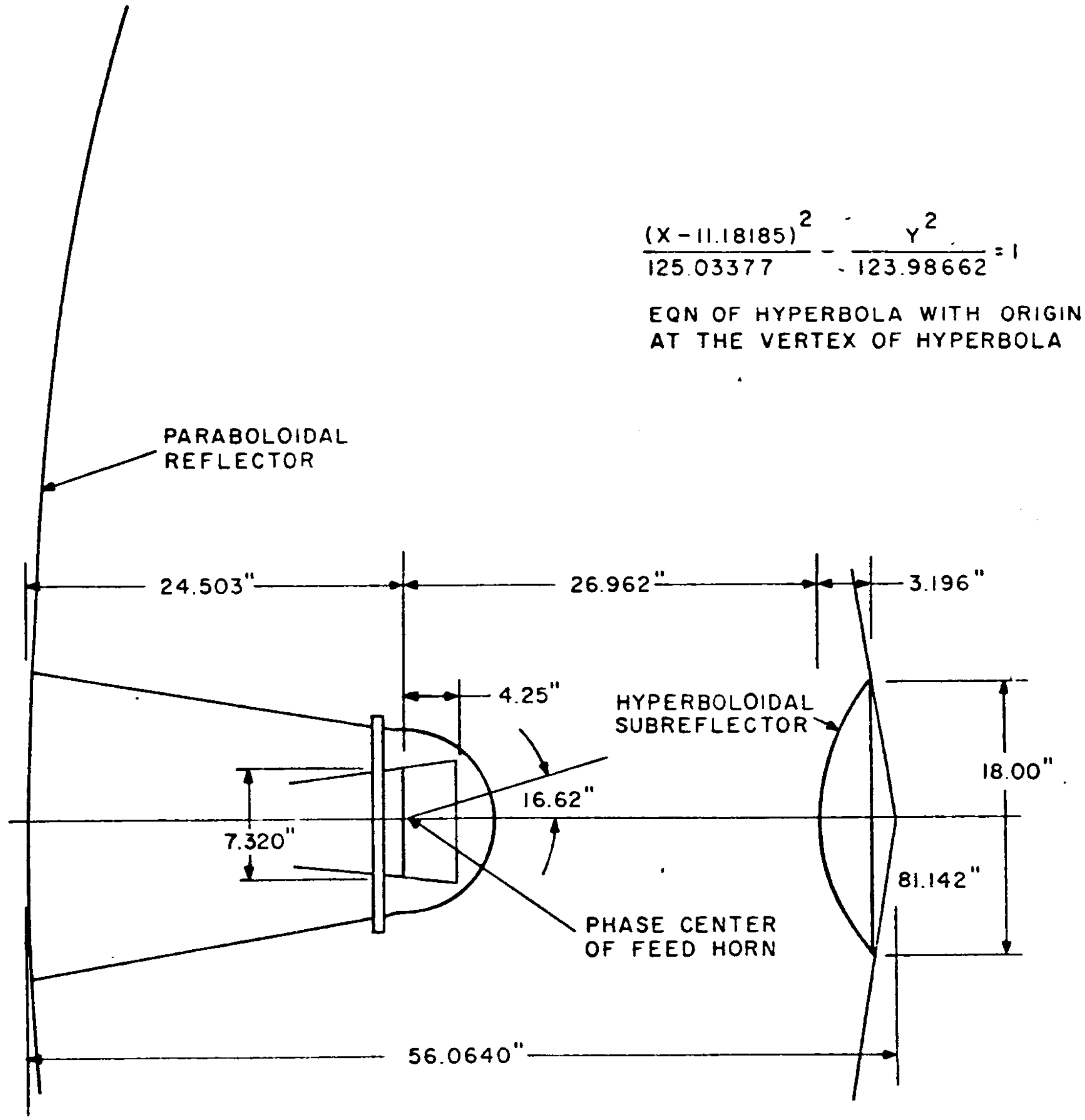


Figure 3.3-3. The Final Design Geometry of the ASIR Cassegrain Antenna

the elevation axis assembly. This structure is designed to transfer the wind loads and inertia from the reflector and elevation axis to the azimuth bearing. Additional braces and tie-down cables are not required to meet specification survival conditions.

Both elevation axis uprights contain cable windup assemblies. An ample number of copper paths are provided for normal use as well as spare conductors for any future requirements. In addition one upright contains the chassis associated with the elevation digital encoder. Also mounted on the turntable is the hydraulic supply pump and electric motor which will supply hydraulic oil to both drive motors. Both drive gear boxes are fixed to the turntable.

The antenna pedestal assembly is designed to permit unobstructed tracking to a depression of -10° at any azimuth angle. This permits consideration of the roll and pitch angular motion and allows horizon tracking under sea conditions as specified. At -10° and $+190^\circ$ the elevation axis assembly encounters the elevation buffers. These buffers work through an additional 5° before they bottom out. During this 5° buffering stroke the kinetic energy of the elevation axis assembly is absorbed and thus the shock load is reduced should the elevation axis be driven beyond the limits. Elevation buffering is accomplished by a hydraulic mechanical spring.

The on-mount gyros are located close to the azimuth and elevation axes. Small departure from the theoretical "on-axis" location have negligible cross-roll components and therefore introduce an insignificant amount of error into the system.

The alignment of the RF axis is determined by an optical boresight operation made at dockside. The exactness of alignment may be checked at sea by running boresight checks against balloon-borne spheres. Adjustment is built into the hyperbolic secondary reflector and the Versatel lens mount to align the system.

3.4.3 Elevation Assembly

The elevation axis assembly rotates about the elevation axis on preloaded precision ball and/or roller bearing pillow blocks which are carefully phased to provide minimum gearing eccentricity. The pillow blocks are supported by the turntable uprights. The reflector is mounted directly to the rotating elevation housing which is located between the uprights.

An extension of the elevation axis shaft is provided to support the 80/40-inch Versatel lens system, television camera and film camera. An eyepiece is provided with the Versatel lens for boresight operations. Counterweights are provided in the elevation assembly to statically balance the rotating assembly about the elevation axis.

The elevation data gear box is attached to one of the uprights. It is driven directly by a torque tube from the trunion shaft. It is essentially identical to the azimuth data gear box.

3.4.4 Pedestal Design Features

The antenna-pedestal is capable of being locked in any attitude in both elevation and azimuth by means of static electric brakes. This permits efficient boresighting and other servicing techniques.

To ensure temperature stability the basic structure of the pedestal is heavy steel fabrication. This results in an almost 2:1 reduction in thermal expansion over aluminum alloy construction due to the lower coefficient of thermal expansion exhibited by steel. The heavy sections act as heat sinks and provide paths for equalization of differential temperature gradients.

In addition, the entire antenna pedestal is finished with a special paint specifically selected to minimize absorption of solar radiation.

To meet the specified environmental conditions, all parts of the pedestal are protected by special finishes, gasketed covers, hermetic sealing and use of non-corrosive materials and components. All external motors and blowers are totally enclosed, all hydraulic components are rust proofed or made of stainless steel. Interfaces are weather sealed and the best assembly techniques are used to ensure minimum maintenance.

The mount is equipped with sound power phone jacks in each axis to permit communication between the pedestal location and other portions of the radar system.

The power drive system consists of a pumping circuit, heat exchanger, control circuitry, and two power drives. The prime power is a 20-hp motor. Controls are provided for a well regulated pressure over all ranges of flow and pressure. A special circuit is provided to limit system pressure for normal operation and provide higher pressure for maximum performance conditions in high winds. This variation in pressure capability adds to the life and reliability of the system. The power drive is controlled with a "linearized" valve to provide wide dynamic range over the operational requirements of the equipment.

The power gearing on both axes is provided with anti-backlash devices. The azimuth axis has a mechanical preload between drive pinions. The elevation gear box is pivoted against the bull gear to preload the mesh. The azimuth and elevation axis data systems have excellent compatibility with existing range systems and meet the requirements of the specification. This mount provides similar synchro outputs as the AN/FPS-16, Mod 0 and the AN/FPQ-6. Seventeen bit, two-speed digital data outputs are provided on both the azimuth and elevation axis.

3.5 RECEIVERS

The ASIR IF receiver subsystem is similar to the basic AN/FPS-16 receiver. An acquisition channel has been added and the AFC systems have been modified.

Figure 3.5-1 shows a block diagram of the IF receivers. Angle tracking error signals are developed in a conventional three-channel monopulse system. The reference channel composed of the mixer, pre-amplifier, main IF amplifier, phase shifter and gated reference detector develops gated video for AGC, range tracking and displays. The AGC signal is applied to the reference, azimuth error and elevation error channels to normalize the reference to error signal at the error detectors with input signal dynamic range. The phase shifters provide static phase adjustment between channels. The error signal is developed in the error detectors after range gating by comparing the error IF signal to the reference IF signal.

An ungated, AGC'd video signal is developed from the reference IF signal in the ungated IF amplifier.

The acquisition channel has been added and replaces the ungated (non-track) IF of the basic AN/FPS-16. An output of the reference pre-amplifier is processed in a main IF amplifier and ungated IF amplifier. Gain control is established by the range tracker based on signal level threshold in the IF bandwidths of the system.

The ASIR AFC system incorporates a variation of the 5000-mile DIRAM modification to the basic AN/FPS-16. The system provides skin and beacon AFC. The skin AFC has the facility of utilizing either the skin return or the transmitter sample as the reference signal. In addition, the system provides coast or memory by AFC deactivation during return signal fade. In beacon AFC mode, a signal from the reference IF pre-amplifier is AGC'd and gated for use in the AFC servo amplifier. The signal is then discriminated and converted to a DC drive for the beacon AFC servo motor unit. The motor unit in turn provides a DC control voltage for the beacon local oscillator. In the event a target signal fades, a low signal-to-noise ratio is detected by a comparator in the AFC deactivation unit. The comparator in the deactivation unit thresholds the beacon AGC voltage, develops a relay control signal which when applied through the AFC servo amplifier removes the control signal from the motor unit. The beacon LO control voltage then remains at its last value until the return of the IF signal.

Skin AFC on the return signal operates very similar to beacon AFC. The discriminated signal is passed from the AFC servo amplifier, through the AFC deactivation unit to the skin LO control circuits. On loss of IF signal the motor unit is again deactivated as in the beacon mode. During skin AFC when using the transmitter sample as the reference, the skin AFC unit is fully utilized. The RF skin LO and transmitter sample are mixed to provide a 30-Mc IF signal. The frequency discriminated signal is then used in a phantastron circuit to develop the skin LO control voltage.

The principal differences between the ASIR receiver design and the basic AN/FPS-16 are discussed in the following paragraphs.

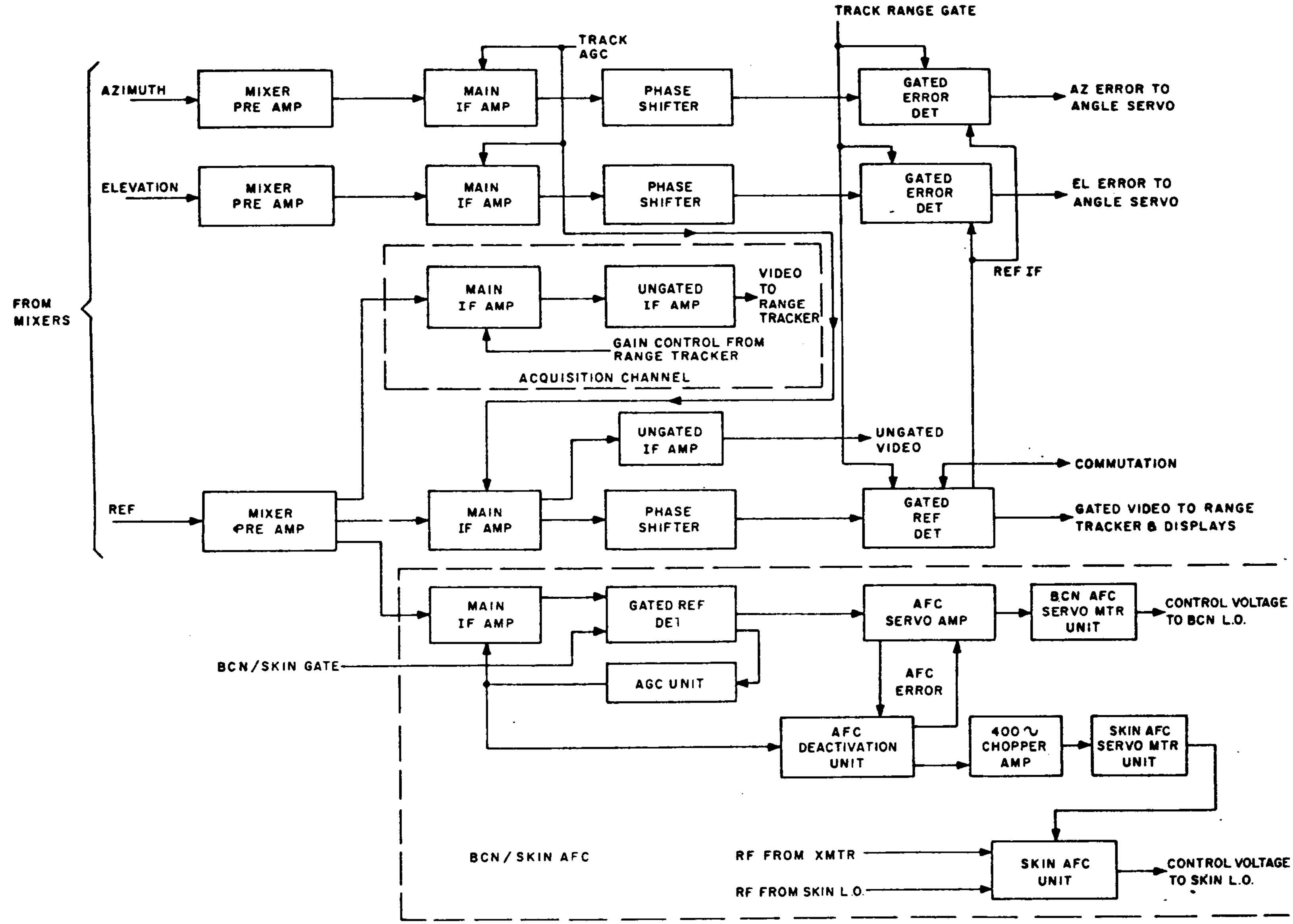


Figure 3.5-1. Functional Block Diagram of the Receiver Subsystem

3.5.1 Acquisition Video Channel

The non-track IF amplifier that is normally provided in the AN/FPS-16 radar has been replaced by a more satisfactory amplification channel. The non-track output of the reference pre-amplifier in the RF head is used as an input to an additional main IF amplifier. The main IF output is then supplied to an additional ungated IF amplifier whose video output provides an acquisition and display signal to the range tracker.

The acquisition channel comprising the above mentioned main IF amplifier and ungated IF amplifier accepts a gain control voltage whose level is established by the range tracker.

This change was made to enhance range tracker acquisition by providing an IF channel which is the same as the normal reference channel.

3.5.2 Range-Gate Level

The level of the range gates provided to the receiver in the ASIR system dictated a change in the gated reference detector and gated error detector units. The range gate driver circuits were modified to accept a 40-volt input gate level.

This signal is developed in the range tracker from transistor circuits, and the 40-volt gate is the practical upper limit due to power considerations.

3.5.3 AFC Deactivation Unit

The AFC deactivation unit was added to prevent drift of the LO's when the S/N of the received signal is low. Deactivation of the AFC is initiated whenever the AGC Voltage exceeds a predetermined threshold and remains in effect as long as the received signal is too weak to maintain proper AFC control.

3.6 ANGLE SERVOS

The ASIR servo equipment configuration closely parallels the design used on the most recent shipboard version of the AN/FPS-16, Serial No. 46, now installed aboard Missile Range Instrumentation Ship AGM-8. The AGM-8 servo uses a valve-motor hydraulic drive with vacuum-tube electronic control chassis. The AGM-8 servo equipment configuration was basically sustained on the ASIR servo except that nine chassis units were replaced by one new solid-state chassis, the stabilization amplifier, to process on-mount gyro signals not required for the AGM-8 design.

The angle servo equipment configuration is functionally shown in Figure 3.6-1 and consists of control electronics located in the ship's radar control complex and drive and data take-off components located on the pedestal. The servo control electronics are housed in chassis units located in servo bank 152 (see Figure 3.6-2). All chassis except the stabilization amplifier are updated basic AN/FPS-16 vacuum-tube designs with modifications as required for the ASIR application. The stabilization amplifier is a new solid-state electrical design. The mechanical design of this chassis is a hybrid chassis-nest configuration that is mechanically similar and compatible with the basic AN/FPS-16 vacuum-tube chassis.

The servo drive is an improved basic AN/FPS-16 Mod I hydraulic valve-motor drive system that is physically a part of the pedestal configuration (refer to Section 3.4, Pedestal). The data take-off components used by the servo consist of drive motor tachometers, data gear box synchros, elevation limit switches, and load rate gyros. All these components are basic AN/FPS-16 Mod I designs with the exception of the rate gyros. The rate gyros are torsion-bar type transducers requiring no electronic signal processing equipment to produce electrical rate signals. The elevation rate gyro is mounted in the RF head and the bearing rate gyro is mounted in the elevation data gear box.

3.6.1 Design and Performance Specifications

The ASIR servo is designed to meet applicable portions of Specification GSFC-OIS-1, dated 10 July 1964, Rev. B. The ASIR servo design and performance specifications are summarized in Table 3.6-1. Tests performed on the equipment demonstrated that all specifications were achieved.

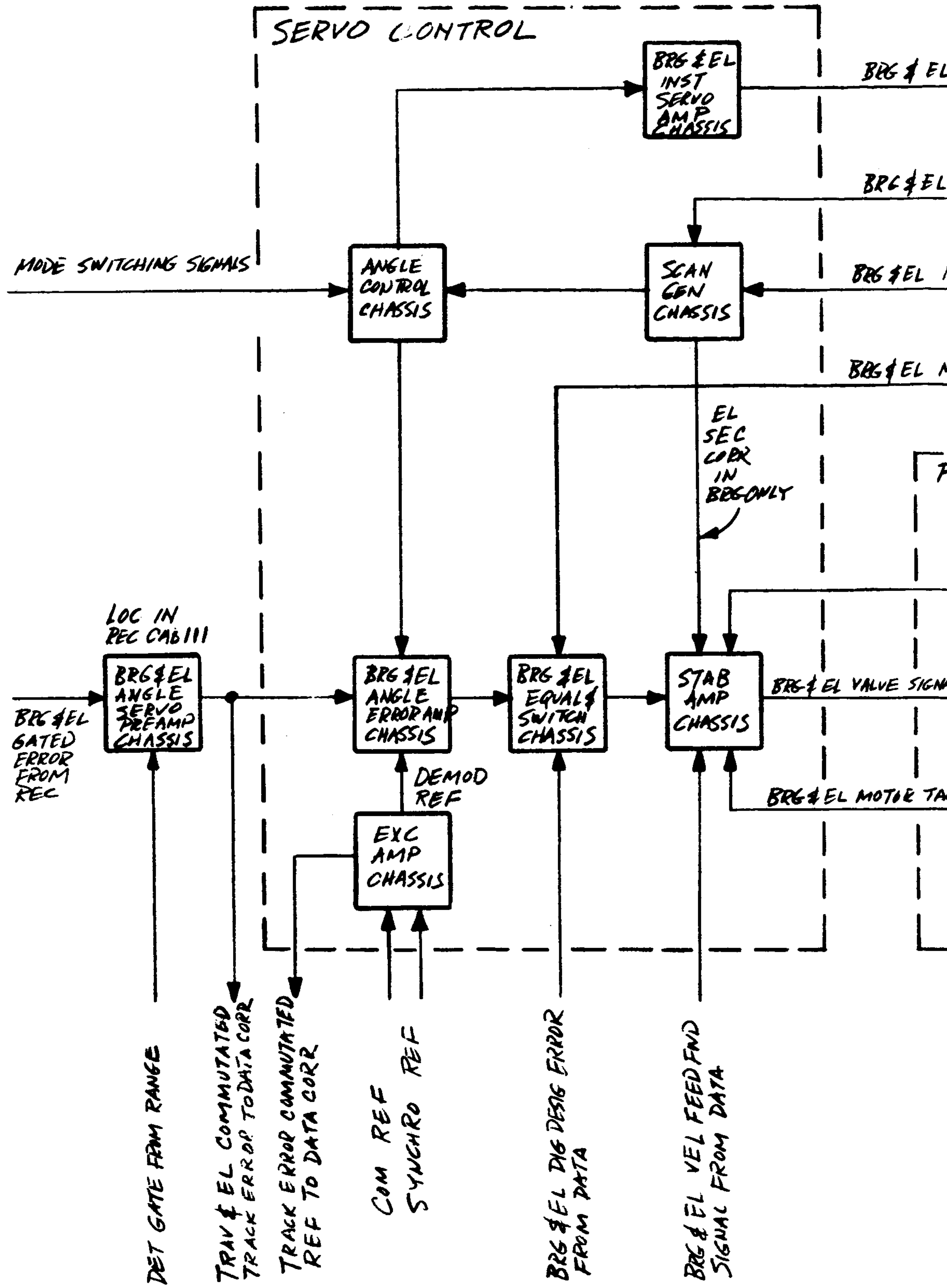
3.6.2 Functional Requirements

The ASIR servo is required to perform the following functions during the radar system auto track, acquisition, and manual modes of operation:

1. During automatic tracking, position loop closures are provided by error signals developed in the monopulse receivers. The servo interfaces with the receiver and range track to process the tracking errors. Operation is with discrete variable bandwidth and coast switching control from the console. Data handling interfaces between the angle servos and the computer to provide digital signals of the servo dynamic lags to the computer for error correction of the target coordination.

2. During acquisition and manual mode, single-speed position loop closures are provided by either 1-speed or 16-speed (manual test mode only) synchros. The servo interfaces with the console for control either with handwheel synchros, fixed position test synchros, or external (slave) synchros. Synchro acquisition position commands can either be stabilized or unstabilized for ship's motion. Stabilization is done via the computer with the stabilization signals provided in analog 3-wire stator line form.

3. For acquisition-mode computer position loop closures, the digital computer is used as the error sensor. Data handling interfaces between the computer and the servo to provide analog error signals to the servo. The computer acquisition mode is stabilized within the computer for ship's motion.


SERVO CONTROL
BRG & EL INST SERVO AMP CHASSIS
BRG & EL
BRG & EL
BRG & EL
BRG & EL
MODE SWITCHING SIGNALS
ANGLE CONTROL CHASSIS
SCAN GEN CHASSIS
EL SEC CORR IN BRG ONLY
LOC IN REC CAB 111
BRG & EL ANGLE SERVO PREAMP CHASSIS
BRG & EL ANGLE ERROR AMP CHASSIS
BRG & EL EQUAL & SWITCH CHASSIS
STAB AMP CHASSIS
BRG & EL VALVE SIGN
BRG & EL GATED ERROR FROM REC
DEMOD REF
EXC AMP CHASSIS
BRG & EL MOTOR TA
DET GATE FROM RANGE
TRAV & EL COMMUTATED TRACK ERROR TO DATA CORR
TRACK ERROR COMMUTATED REF TO DATA CORR
COM REF
SYNCHRO REF
BRG & EL DIG DESIG ERROR FROM DATA
BRG & EL VEL FEED FWD SIGNAL FROM DATA

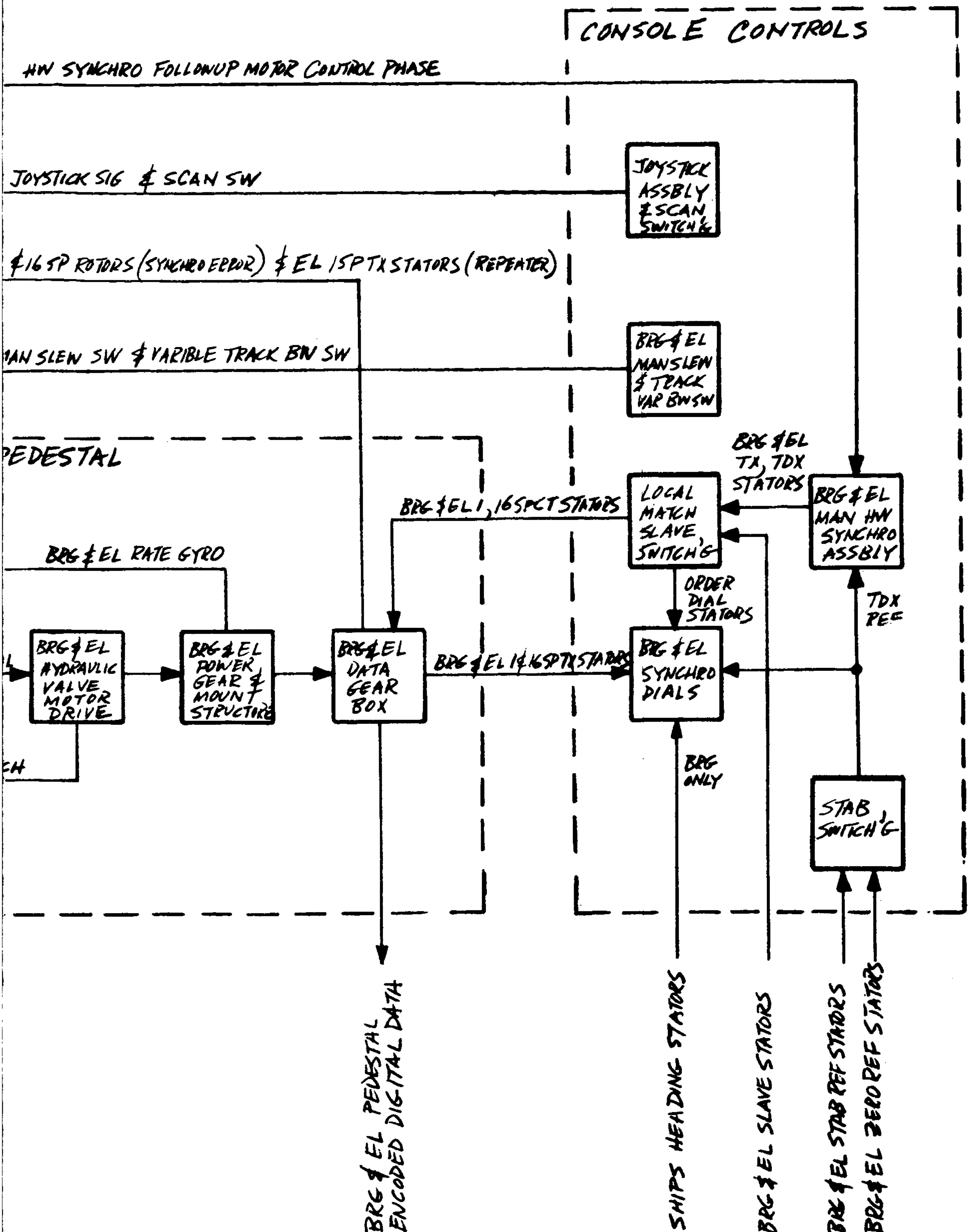


Figure 3.6-1. ASIR Servo & Control System Functional Block Diagram

Servo Bank 152
8750547-501

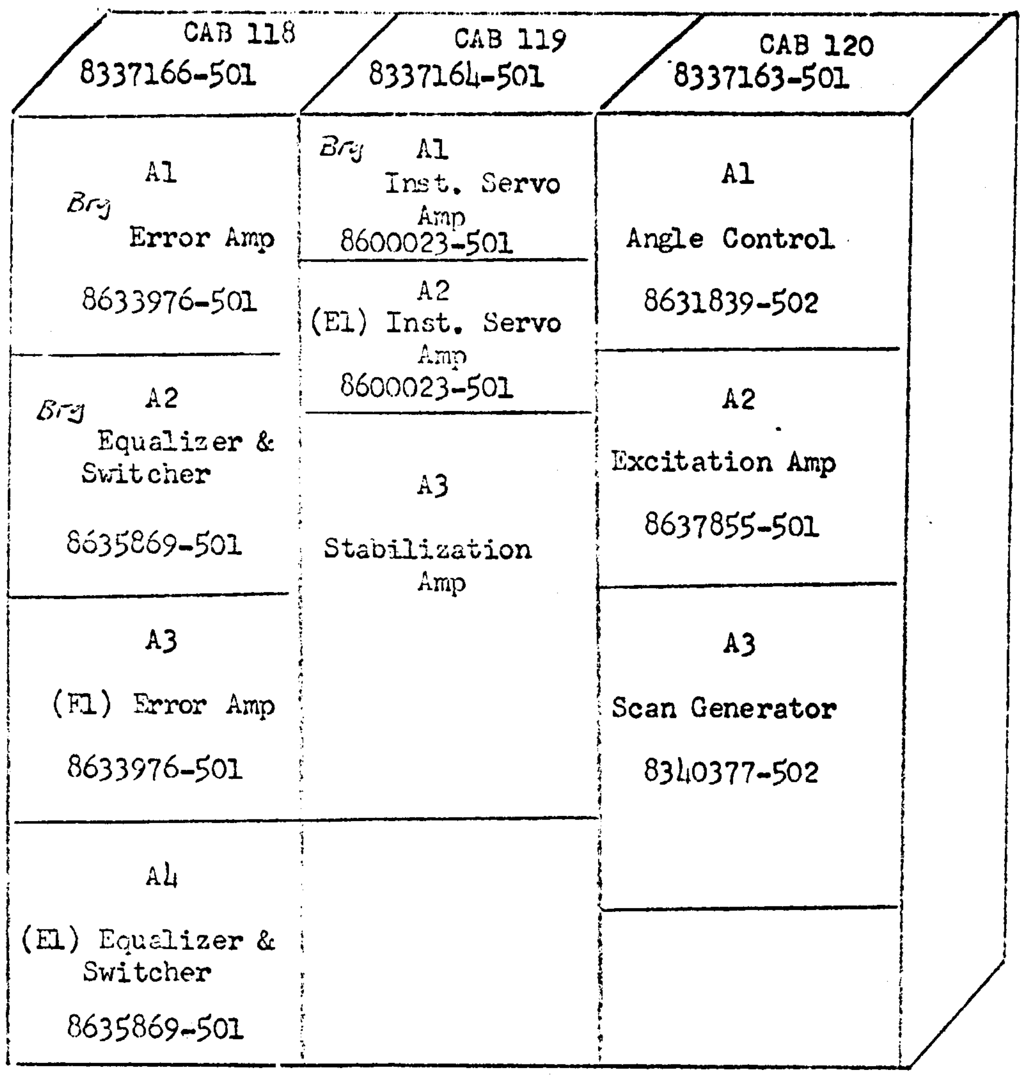


Figure 3.6-2. ASIR Servo Control Electronics Equipment

TABLE 3.6-1

ASIR SERVO DESIGN AND PERFORMANCE SPECIFICATIONS

MAXIMUM VELOCITY	
Winds up to 45 knots	800/450 mils/sec (az/el)
Winds up to 60 knots	650/300 mils/sec (az/el)
MAXIMUM ACCELERATION	
Winds up to 45 knots	1.3 rad/sec^2
Winds up to 60 knots	1/0.6 rad/sec^2 (az/el)
TRACK LOOP BANDWIDTH	
*Wide	4.5 cps
Medium	2.5 cps
Narrow	0.9 cps
TRACK LOOP VELOCITY CONSTANT	
*Wide	400 sec^{-1}
Medium	340 sec^{-1}
Narrow	250 sec^{-1}
TRACK LOOP ACCELERATION CONSTANT	
*Wide	50 sec^{-2}
Medium	16 sec^{-2}
Narrow	2 sec^{-2}
TRACK LOOP TORQUE CONSTANT	
*Wide	10 x 10^5 ft-lb/mil
Medium	100/9 x 10^5 ft-lb/mil (w/wo gyro loop)
Narrow	77/7 x 10^5 ft-lb/mil (w/wo gyro loop)
SHIPS MOTION TRACK LOOP ISOLATION	
*Wide	28 db at 0.2 cps
Medium	16 db at 0.2 cps
Narrow	8 db at 0.2 cps
SHIPS MOTION STABILIZATION ISOLATION	
Gyro loop	20 db up to 0.2 cps
Velocity feed forward	14 db up to 0.2 cps
SHIPS MOTION TOTAL ISOLATION	
*Wide	42 db at 0.2 cps
Medium	50 db at 0.2 cps
Narrow	42 db at 0.2 cps
ACQUISITION LOOP	
Coarse to fine threshold	25 mils
Bandwidth	0.9/2.5 cps (coarse/fine)
Velocity constant	4/75 sec^{-1} (coarse/fine)
Acceleration constant	2/16 sec^{-2} (coarse/fine)
Torque constant	1/20 x 10^4 ft-lb/mil (coarse/fine)

*Gyro loop disallowed during wide bandwidth operation.

TABLE 3.6-1. (con't.)

ASIR SERVO DESIGN AND PERFORMANCE SPECIFICATIONS

TACH LOOP	
Low frequency loop gain	14 db up to 0.2 cps
Closed loop gradient	125 mils/sec/VDC at pedestal
Closed loop bandwidth	7/6 cps at motor (az/el)
GYRO LOOP	
Low frequency loop gain	20 db up to 0.2 cps
Closed loop gradient	125 mils/sec/VDC at pedestal
Closed loop bandwidth	6.5 cps at pedestal
HYDRAULIC DRIVE SYSTEM	
Prime mover	20 hp, 3Ø, 220V, 60 cps induction motor
Drive motors per axis	2/1 (az/el)
Supply pressure	2400/1400 psi (operate/test)
Maximum flow	120/80/40 in^3/sec (total/az/el)
Total motor stall torque	48/30 ft-lb (az/el)
No load speed	3200/2400 rpm (az/el)
Continuous rated speed	2400/1800 rpm (az/el)
Continuous rated torque	24/14.6 ft-lb (az/el)
Continuous rated power output	16/11/5 hp (total/az/el)
Servo valve input at maximum flow	8/4 ma (az/el)
System leakage	6/4/2 in^3/sec (total/az/el)
Total motor stiction	8/4 ft-lb (az/el)
Reflected load stiction & unbalance	0.3/0.3 ft-lb (az/el)
Total motor and pinion inertia	0.043/0.025 slug-ft^2 (az/el)
Reflected load inertia	0.043/0.021 slug-ft^2 (az/el)
Reflected wind torque	15/13 ft-lb peak at 45 knots (az/el) 7.5/6.5 ft-lb rms at 45 knots (az/el)
Gear ratio	360/405 (az/el)
MECHANICAL RESONANT FREQUENCIES	
Hydraulic oil	5/7 cps (az/el)
Locked rotor	16/10 cps (az/el)
Free rotor	22/14 cps (az/el)
Antenna	20/18 cps (az/el)
STABILITY	
Loop gain margins	7 db minimum all loops
Loop phase margins	45° minimum all loops

4. On-mount bearing- and elevation-rate gyro loop closures can be selected at the console for stabilization (isolation) of ship's motion during automatic tracking.

5. Servo drive motor tach loop closures are provided to compensate the servo drive system and reflected load transfer characteristics. The motor tach loops are also used to further stabilize (isolate) ship's motion using digitally computed ship's motion bearing and elevation velocity feed-forward. Data handling interfaces between the computer and servo to provide analog velocity command signals to the servos.

6. Analog scan generation and joystick offset are used in the synchro acquisition mode. These functions are digitally performed within the computer in computer acquisition mode. The servo interfaces with the console for analog scan and joystick control. The servo interfaces with data handling to provide either analog or digital scan display signals to the console.

7. During the manual test mode, control of the manual slew operation is provided from the console.

8. The angle servos enable pedestal position followup of the console handwheel synchros during track operation, manual slew operation, and initial mode switching of handwheel synchro operation.

3.6.3 Design History

No major problems were encountered during design and development of the ASIR angle servos. Several minor switching and equalization network changes were made. The traverse axis rate gyro was relocated to the bearing axis because of the difficulty in stabilizing the gyro loop at high elevation angles. The gyro relocation change required minor cabling and stabilization amplifier circuit interconnection changes.

3.7 RANGE TRACKER

The range tracker subsystem consists of twenty-two module nests, six chassis, two control panels, and four power supplies. A total of 441 modules are required utilizing 65 different module types. The equipment is housed in six standard rack-type cabinets that are grouped into three pairs allowing Cabinets 121 and 122, 123 and 124, and 125 and 126 to be separated for ease of shipment and installation. Interconnection is made between the pairs by terminal boards.

The Advanced Digital RANge tracker (ADRAN) employs solid-state digital techniques to provide continuous, unambiguous range data on targets from 500 yards to 32,000 miles with a capability for expansion to 256,000 miles. This range tracker shares several components with the auxiliary tracking (auxtrack) unit and although auxtrack is primarily intended as an acquisition aid, it is considered in this report as part of the range tracker subsystem.

Range designation information in serial form can be accepted from either of two external sources. The range detection section uses a statistical evaluation process to determine target presence in a ten-mile region about the designated position. The system employs double-threshold detection by means of binary quantizer integration and m-out-of-n detection. A recirculating delay-line integrator is used to store m sweeps. These m samples are updated each PRF with a new data sample replacing the oldest stored sample. The count sampler indicates target presence. The information is not "dunked" after n integrations as in previous DIgital RAnge Machines (DIRAMs).

The range servo loop is an all-electronic type-II system with six discrete bandwidths selectable from 0.5 to 16 cps. A continuously variable slew from 0 to 30,000 yards per second and a fast slew of 240,000 yards per second are provided.

The range tracker in the track mode utilizes a type-II servo configuration with a maximum acceleration constant (Ka) of 2500 sec^{-2}. The maximum tracking rate is in excess of 20,000 yards per second; the maximum slew rate is 240,000 yards per second. Acceleration capability at maximum bandwidth is 10,000 g; the widest closed-loop tracking bandwidth is in excess of 15 cps. The range system is capable of delivering continuous, unambiguous range tracking data on suitable targets to a maximum range of 32,000 nautical miles; the output data format is 25-bit binary, with a granularity of two yards. The internal random error of the range tracker is approximately 2.5 yards rms, exclusive of thermal tracking error, propagation effects and beacon error.

3.7.1 Range Designation and Tracking

Range designation data in serial form supplied from a source external to the range tracker are stored in a range counter and compared with range reference data from the reference counter (see Figure 3.7-1). The range reference data are generated by a precision, synchronized clock. Upon coincidence of the reference and designation data, an appropriate clock pulse is selected. This pulse, after passing through an interpolation circuit, serves as the range gate trigger.

A closed loop is created to provide automatic tracking after a target is located. The range gate trigger initiates the generation of the receiver gate and the early and late gates for the range discriminator. The receiver gate is used to introduce to the gated reference and error detectors only those signal returns coinciding with the range gate. The early and late discriminator gates facilitate generation of a range error (the displacement of the target return from the center of the receiver gate).

The resulting DC range error voltage is converted by an operational integrator to a pulse train whose frequency is proportional to the magnitude of the range error voltage. These pulses are then fed back to the range counter to correct the range reading in the counter. The direction of required correction is determined by an error polarity sensor which appropriately actuates a forward-backward bus to the range counter that causes the counter to count up or down as required. The analog-voltage-to-pulse-frequency converter is also a servo integrator.

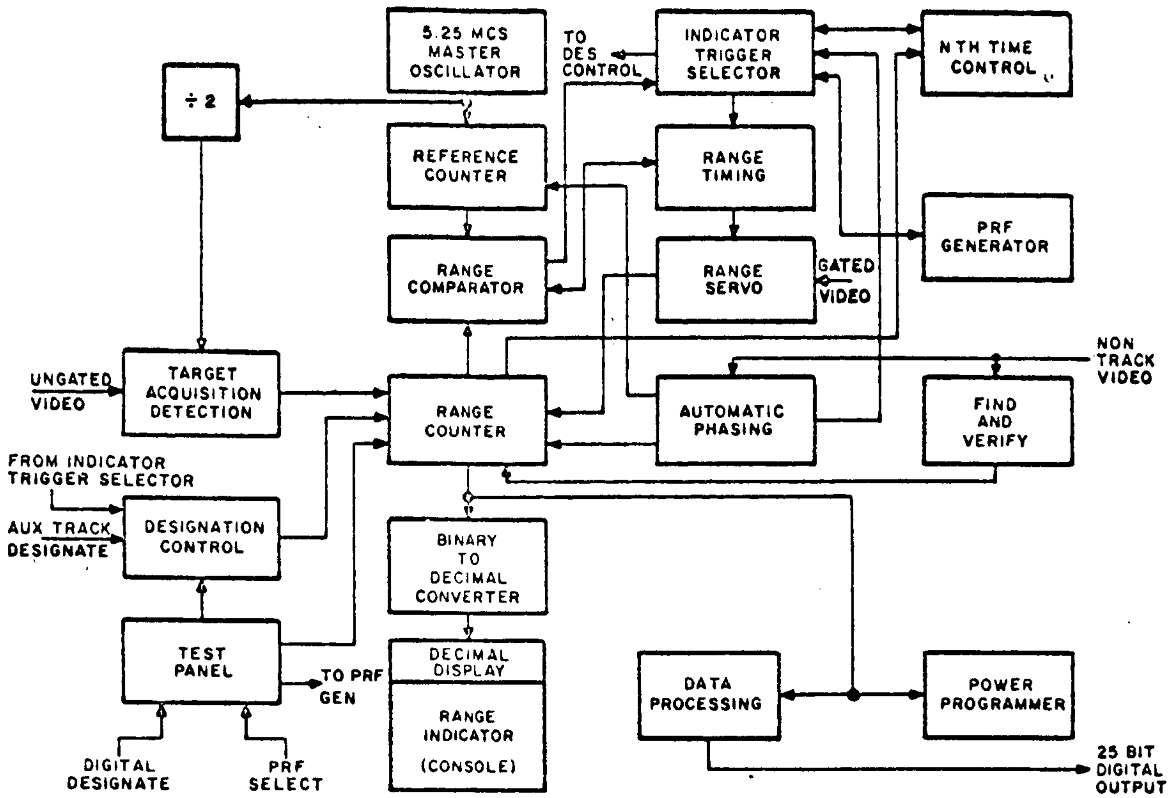


Figure 3.7-1. Block Diagram of Advanced Digital Ranging System

The digital ranging system has the capability for continuously tracking targets using a PRF much higher than the maximum unambiguous value. True range is always present in the range counter; this is accomplished by appropriately grouping the coincidence circuit stages at certain repetition rates so that the range gate is generated at the target apparent (i.e., ambiguous) range even though the value in the range counters is the true range. This Nth-time-around tracking capability is provided at the 160-pps and 640-pps repetition rates.

3.7.2 Multiple-Gate Acquisition

For target detection, a statistical evaluation method is employed. Basically, whenever ungated video crosses a threshold with a positive slope, a standard pulse is generated. These quantized video pulses are gated through 20 acquisition gates, each of 1,000 yards duration, for a total of 20,000-yard search region (±10,000 yards about the designated range).

The false alarm rate is maintained constant by a feed back of the quantized video pulses into a circuit which readjusts the video threshold as the noise level changes. The threshold is regulated to maintain the number of crossings per second at a fixed rate and thus the probability of false alarm is established at a constant value. This constant-false-alarm circuit is employed to avoid erroneous counts resulting from changes in the ungated video level. The average number of quantized video pulses is monitored and the video quantizer threshold level is automatically adjusted if the average value of the ungated video should change.

The outputs of each of the twenty gates are stored in a sonic delay line, each PRF, up to 60 twenty-bit words are stored and updated each PRF. The data is read out as 20 sixty-bit words, sixty bits for each gate. If 30 of the sixty bits in any one gate show "yes" to target presence, a signal is sent to the range counter to center the range gate over the acquisition gate showing target presence and acquisition is completed to automatic track.

Target detection is based on the premise that with the proper threshold settings, the counters corresponding to the search gates containing only noise have an average noise count with a known variance, but the gate containing the target has a higher average count since the mixed signal should exceed the threshold more often than noise alone. Thus, by examining a predetermined number of radar periods target presence within the gate is ascertainable.

The digital range tracker is capable of employing Nth-time-around echoes for acquisition and tracking in order to provide a high probability of detection and high tracking accuracy. When the target is being tracked, the range equipment provides unambiguous range output while still tracking Nth-time-around returns. The problem of the target returns coinciding with the transmitted pulses as the target changes in range is overcome by a pulse delay technique (described later) which essentially does not alter the radar PRF.

For a target moving at a rate of 20,000 yards per sec, using a PRF of 640 pps, a one-microsecond transmitter pulse width, and an input signal to noise ratio of 10 db, the probability of detection during a thirty (30) millisecond interval was determined to be 99.9% with a false-alarm probability of 10^{-4}. In case of a stationary target, using a PRF of 640 pps, a one-microsecond transmitter pulse width, and an input signal to noise ratio of 3 db, the probability of detection during a ninety (90) millisecond interval was measured to be 99.9% with a false-alarm probability of 10^{-4}. Using the advanced technique of constant integration without dunking during acquisition improves the probability of detection during any specified time after target appearance in any given acquisition gate.

3.7.3 Nth-Time-Around Tracking

Tracking an object at ranges in excess of the radar time base is accomplished in the digital ranging system by a multiple-time-around technique, rather than through reduction of the radar PRF. This method maintains the sampling rate at extended ranges but does pose two unique problems; first, the elimination of possible interference by the transmitter pulse and certain conditions between the transmitter pulse and the returning clutter energy, and second, the resolution of ambiguous range in the absence of designation data.

The method by which the range tracker utilizes an increased sampling rate free of range ambiguities will be described first. The reference counter, capable of counting to 2^{21}, accepts the 5.25-Mc clock pulse input. The count is completed, nominally, every 0.4 second. Repetition rates of 160 or 640 pps are used in the Nth-time-around mode and are derived, respectively, from the fifteenth and thirteenth stages of the reference counter. These pulse trains are utilized as radar pre-triggers, and in turn, force the generation of a modulator trigger. Thus, for the full reference count (which is equivalent to a range of over 32,000 miles) 64 or 256 RF transmissions may occur, depending on the repetition rate, before a return from the first RF transmission is received.

Consider now the production of the range gate. The range gate trigger would occur at a 2-1/2 pps rate if no modifications were made to the range comparator circuit. This limitation would result because the numbers in the reference counter and range counter must be the same before the succeeding clock pulse is allowed to pass through the comparator and be used essentially as the range-gate trigger. The digital range tracker overcomes this restriction by increasing the frequency of the range-gate triggers to correspond to the number of transmissions. This is accomplished by grouping stages of the comparator to provide range-gate triggers at the apparent range of the target, i.e., the time after each transmitter pulse at which a target return occurs. Thus the sampling rate of a target at extreme range may be increased by a factor of 64 or 256, depending on the pulse repetition frequency being used.

3.7.3.1 Method of Avoiding Transmitter Pulse Interference

As a target moves from zone n to zone n+1, or in the opposite direction, the transmitted and received pulses are in close proximity. (Zone n may be defined as the range interval between the nth and nth+1 transmitted pulses.) There is a possibility of the system losing the echo at this time because of transmitter-pulse leakage and clutter, and instead, locking on the transmitter pulse or clutter. To avoid such an occurrence, the system introduces an alternating transmitter-pulse-range-gate delay sequence.

The method enables time separation of the transmitter pulses and target returns when the received signals are in the pre-determined interference zone without changing the sampling rate. The pulse-repetition rate for Nth-time-around tracking, as previously mentioned, is either 160 or 640 pps, and for either PRF the established interference region is adjustable to 32,000 yards; the range system starts the alternating delay sequence when interference is imminent and maintains it until the first delayed echo is received. The delay is then shifted to the receiving channel and retained there until reception of the signal from the last delayed transmitted pulse. The operation is repeated until the target moves out of the interference region. The technique requires that target range be accurately known in order to remove the delay in the transmitter channel and insert it in the receiving channel at the appropriate time.

The range counter number is in binary form and may be regarded as being composed of two parts, namely; a zone number and an apparent range number. At a pulse-recurrence rate of 640 pps, the last eight stages of the 25-stage range counter contain the zone number while for a repetition rate of 160 pps, the zone information is in only the last six counter stages. The remaining stages in the range counter contain the apparent range number.

Identification of range positions near or in an interference region is readily accomplished since the repetition rates are fixed. Stages 14 through 21 operating at a PRF of 160 pps, and stages 14 through 19 for the pulse-recurrence rate of 640 pps are the zone stages. Whenever these stages contain all logical ones or all logical zeros, interference is imminent, that is, the target position is such that a return will arrive at the receiver at the time that an RF transmitted pulse with its ground clutter is present. All logical ones denote a target passing from zone n into zone n+1 and all logical zeros indicate passage from zone n into zone n-1.

Reiterating, the interference between an echo and RF transmission is avoided by initially introducing a delay into the transmitter channel. The delayed pulse is obtained by selecting for the "main-bang" trigger a different pulse in the 16-kiloyard train. This pulse train is available from stage 9 of the reference counter.

The number of delayed transmitted pulses depends on the number in the zone-identification stages of the range counter. For example, if the target were in a fifth-time-around zone and entering the sixth (logical-one interference region), five transmitter pulses would be delayed. If the target were entering the fourth zone (logical-zero interference region), only four transmitter pulses would be delayed. Summarizing, n transmitter pulses are delayed followed by n undelayed pulses when a target is in zone n and moving into zone n+1. When the target moves from zone n into zone n-1, n-1 transmitter pulses are delayed.

The other aspect of the problem is to generate the range gate at the appropriate time. In order to track returns resulting from delayed pulses, the range gate triggers are delayed correspondingly by a similar process. Undelayed range gates are generated when the received signals are due to undelayed transmitted pulses.

The Nth-time-around control unit introduces the alternate delays of the modulator trigger and the range gates when the target is in an interference region. In this unit, the number of delayed "main-bang" triggers or range-gate triggers is recorded in the zone counter. This number is then compared with the number occurring in the zone stages of the range counter, a coincidence trigger is obtained when the numbers in both counters are identical. This trigger is used to switch the delay from the "main-bang" trigger to the range-gate trigger or vice versa.

3.7.3.2 Find and Verify Processor

Find and verify are two distinct processes used to resolve range ambiguity and confirm true range in Nth-time-around operation. When a target is acquired without employing designation data, the find mode determines the zone containing the target and the verify mode ascertains whether the zone-counter reading of the range counter is the correct one. After the correct zone is determined, the system converts the apparent range to the true range, by adding the true zone number to the apparent range.

When the track mode is initiated regardless of acquisition method, the verification process is started automatically. Eight attempts to verify are then made. A minimum of four successful verifications out of the eight tries are required for confirmation. Complete verification action requires one reference interval (0.4 sec.). Further action stops should the zone be confirmed. Failure to confirm, that is, less than four successful tries, automatically switches the system to the find mode; a successful try stops the find process and reinitiates the verify mode. These modes may also be started by the operator at the console.

Fundamentally, to find the zone containing the target, two transmitter pulses in succession are delayed 2,000 yards. Concurrently, double range gates are generated in each pulse repetition period, the second gates being displaced 2,000 yards from the normal one. The second gate in each pulse repetition period is examined for target presence. The number of transmissions relative to the delayed ones are counted; returns appearing in two secondary gates in sequence in two repetition periods are assumed to be the result of the delayed transmitter pulses and hence the zone is determined. The zone stages of the range counter are then changed appropriately and the verify process is initiated.

To verify, every other transmitter pulse is delayed by a sequence of 2, 4, 6, 8, 8, 6, 4, 2 thousand yards. The range gates following the assumed zone is delayed in the same sequence. If four of the eight delayed range gates contain a return that exceeds a preset threshold, the assumed zone is confirmed.

3.7.4 Automatic PRF Phasing

A PRF phase sequencer unit is included in the range tracker to eliminate beacon interference caused by radars in a tracking chain. If beacon-interrogation pulses from two radars arrive at a beacon target nearly simultaneously, one of the interrogating pulses may be ineffective since a finite time is required for the missile-borne transponder to recover after the reception of a transmission. Moreover, both radars would probably intercept the beacon signal producing a false range indication on one set. Another detrimental effect is the receipt of two closely spaced returns at the two radars if both transmitter pulses trigger the beacon at slightly different times. The sequencer unit automatically phases the RF transmissions of the radar so that they will arrive at the beacon at a predetermined time relative to each other.

The answer to the beacon stealing problem is to time the arrival of the interrogation pulses from two or more radars so that no two pulses arrive at the beacon time spaced with an interval of less than the beacon recovery time. This is done by time phasing the firing of the tracking radars transmitter so that no "rabbit" (video pulses moving with respect to the target video) is allowed to come closer to the target video being tracked than a distance representing beacon recovery time. This transmitter rephasing is controlled by early and late guard gates about the range gate. When a "rabbit" arrives coincident with either early or late guard zone gates, the reference oscillator input to the reference counter is interrupted until such a time that the transmitter pulse can occur clear of beacon interference.

To select the proper delay for the transmitter pulse, the correct time during a 128,000 yard "slot" period selected on the condition that during this period, no "rabbits" are received. When a "rabbit" coincides with a guard zone, the rephasing command starts a counter which counts 128,000 yards. Any rabbit received in this time resets the counter. When an all clear occurs the terminating count (128,000 yards) interrupts the reference oscillator which remains shut off until the time of one PRF less 80 kiloyards has passed. At this time the reference counter is gated on, resumes its count and the transmitter is triggered at the correct time for non-interference.

3.7.5 Auxiliary Angle Tracking

The Auxiliary Angle Tracking (auxtrack) equipment provides automatic angle track of a periodic source, either beacon or skin returns. This is independent of normal range gate signal coincidence. The auxiliary track has independent receiver target gating capability and thus can provide gated signals for control of the angle servo.

The console operator, upon acquiring angle track, can depress a control which transfers the reference count into the range counter at the time of the auxiliary receiver gate. This sets the range counter and the find and verify transfer occurs to provide unambiguous range track. The auxtrack continues to track the target so that auxiliary angle tracking can be reinitiated if necessary, letting auxtrack gate the receiver. As long as two targets are in the same beam, auxtrack can track one target while ADRAN tracks the other.

Designation provisions have been made so that the ADRAN system will be designated to, and lock-on to, the target being tracked by the auxtrack system.

3.7.6 Leading Edge Tracking

A console operated control enables an operator to select Lead or Trail Edge Track depending upon whether the target is approaching or leaving the radar position.

The block diagram of the circuit is shown in Figure 3.7-2. When Lead or Trail Edge Track is activated, the receiver gate width is switched to acquisition gate width. This is to prevent a noise unbalance during lead edge track so that the receiver is being gated at the proper time during trail edge track.

The lead/trail edge track circuitry is inserted in both the gated and ungated video channels of both the ADRAN and the auxtrack circuits. The operator, when switching from lead to trail or trail to lead edge track, must reacquire the target.

In trail edge track, a delay is inserted in the target video equal to twice the delay line length, i.e., 1.0 microsecond. Therefore, the range data must be corrected by approximately 165 yards for a correct range reading.

3.7.7 Beacon Encoder

The beacon encoder is an "off-the-shelf" design previously used in the Mercury Network AN/FPS-16's and in the AN/FPQ-6 instrumentation radars.

The equipment consists of two assemblies. The first unit, the reference delay generator, consists of four transistorized modules. The second assembly contains two coder trigger generator units, each of which produces a two-pulse code.

The inputs to the reference delay generator from the range system are the 16,000-yard pre-trigger and 82-kc pips. The output of the generator is then a selected 2,000-yard trigger occurring a fixed time after the -16,000 yard trigger but before zero time. This trigger is then applied to four identical variable delay channels, two in each cover trigger generator. Each channel provides a delay adjustable in 0.1-microsecond increments.

3.7.8 Range Simulator/Exerciser

The Range Simulator/Exerciser (Moving Target) has been developed to provide a realistic target for use in testing and exercising a digital ranging system as provided in the AN/FPQ-6, AN/TPQ-18 and AN/FPS-16 instrumentation radar systems. The described target simulator represents a significant advance in reliability, simplicity and operation over previous simulators.

The proposed range simulator is an independent target generator which will test the digital range tracker by generating a dynamic or static target located at any point in range out to 32,000 nautical miles. The target can be made to move at velocities up to 32,000 yards per second and cooperate exactly as a real target would in order to test the radar Nth-time-around tracking capability, find and verify equipment, target detection, lock-on circuits, and range coast equipment. A block diagram is shown in Figure 3.7-3.

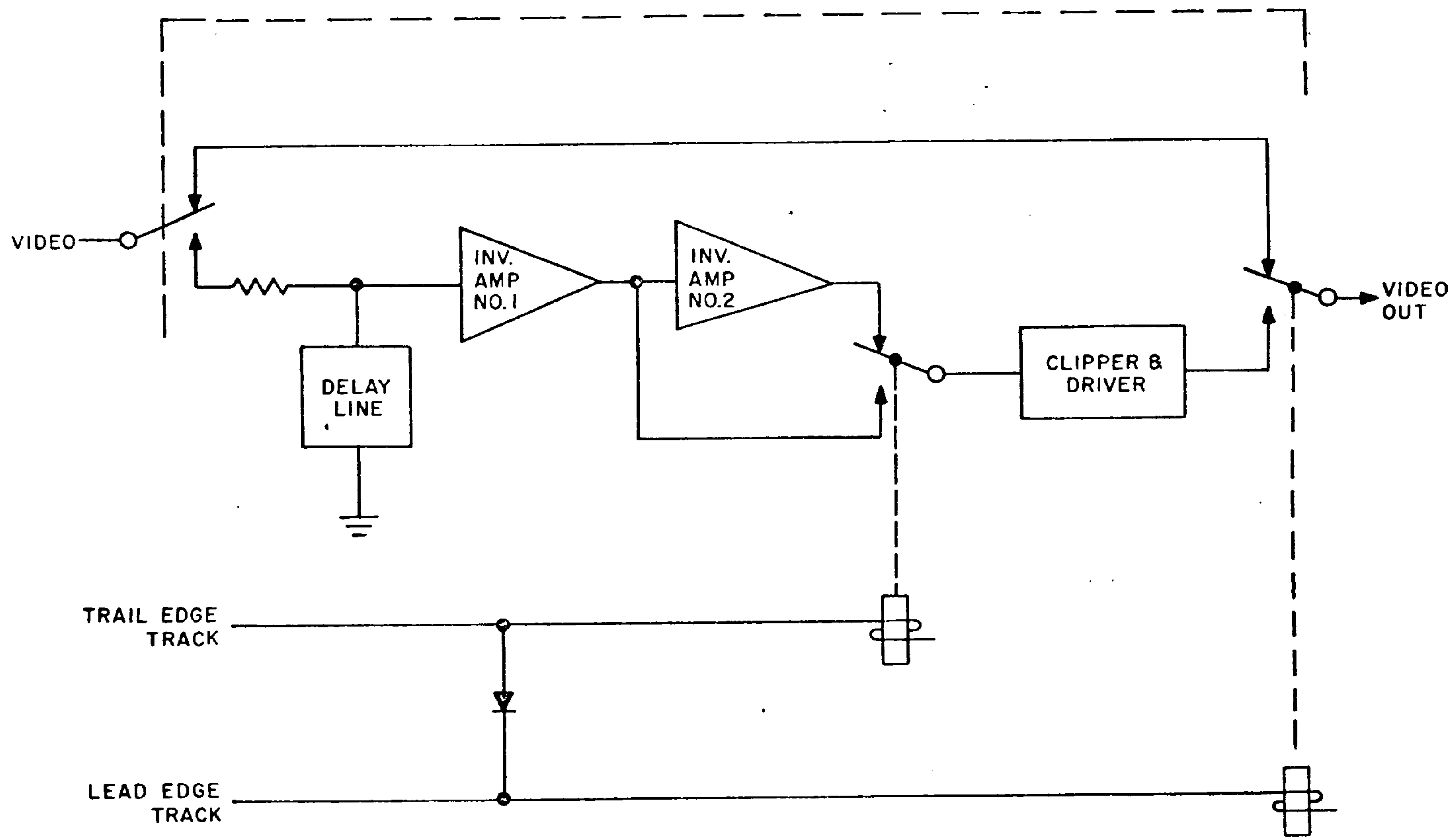


Figure 3.7-2. Block Diagram of Lead/Trail Edge Track Circuit

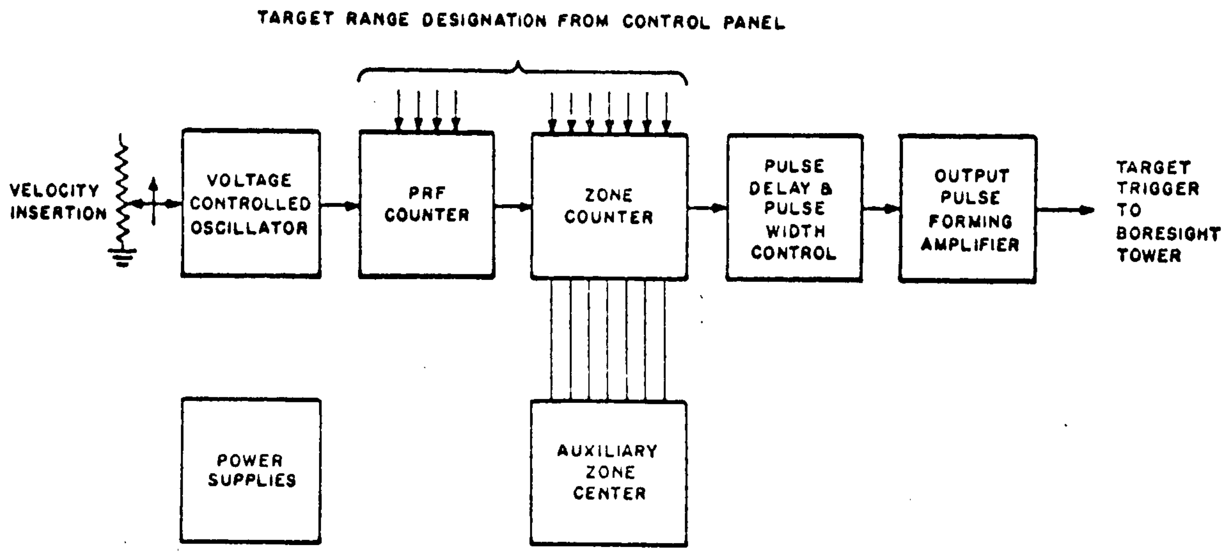


Figure 3.7-3. Simplified Block Diagram of Moving Target Simulator

The range simulator generates static and dynamic targets out to a maximum range of 65,500,000 yards (32,313 n mi). This allows targets to be generated in 256 range zones for a PRF of 640 pps or 64 range zones for the 160 PRF.

The range simulation is an all solid-state design which contributes high reliability, compact size, low heat dissipation and power drain on the existing radar system. Because of its simplified design, the entire unit occupies only two module nests and a control panel.

The simulator is composed of five basic parts: oscillator, PRF counter, digital delay line, designation control, and control panel. The simulator contains its own basic timing oscillator which operates at an approximate multiple of the radar PRF; this frequency is converted into a series of evenly spaced pulses at the oscillator frequency and counted down to the radar PRF rate by the PRF counter. Since the digital range system is implemented for full operation at PRF's of 160 and 640 pps, these two frequencies are the only ones provided by the simulator.

The designation control determines the apparent range position at which the target output pulse should occur, and causes the PRF counter to reach its maximum count at this time, which causes an output target pulse to occur. The digital delay line is a digital counter which counts the zones in which the target pulse should be located, and delays the target pulses from the PRF counter until the zone occurs in which the target is located. At that time, the target pulse is transmitted through the output driver via cable to the boresight equipment, where a pulse of RF energy is transmitted during the time the target pulse exists.

While the ship is in port, therefore, the range system may be tested by way of the normal radar receiver output. At sea, the blocking oscillator output will be applied to a video signal generator which will be included in the complement of commercial test equipment which the Government will supply. The output of the video generator is then injected into the digital range unit at an appropriate point.

The control panel provides a convenient means of designating targets to the desired range and of inserting the desired target velocity into the simulator.

3.8 RADAR CONSOLE

The tracking radar console provides the necessary controls, displays and monitors to accomplish signal acquisition and tracking of missile and satellite targets. Successful operation of the radar depends upon effective communications between the operators and the radar system through the man-machine interface, the console. The application of human engineering principles, combined with a thorough knowledge of range requirements, has produced an optimum arrangement of the console controls and indicators. The console for the ASIR system displays with a maximum clarity the information required to successfully acquire and track a target through both manual and automatic techniques.

The console can be manned by either one or two operators. Prime target-acquisition responsibility is assigned the angle control operator (the right-hand position) and prime tracking responsibility to the range operator (the left-hand position). Panel controls are arranged to separate their functions but yet allow one operator to support the other during peak periods of operational activity. The two operators are directly concerned with the scope display and control portion of the console directly in front of them. Controls and indicators not directly associated with the acquisition and tracking operations are located on the top panels or to one side of the operators. Typical of this control category would be pulse width, pulse repetition frequency, and receiver bandwidth selection controls.

The console consists of essentially four racks with two sloping panels and desk tops in each rack to form the operational console. The eight panels comprising the console and their basic functions are listed below. (Detailed descriptions of the individual controls and indicators are in Section 3-3c of the Technical Manual for Radar Set, Model AN/FPS-16(V).

1. Angle Acquisition Control-Indicator

   Displays position of antenna and any targets with respect to designated position on a C-scope. Provides selection of the antenna scan pattern.

2. Pedestal/System Status Control-Indicator

   Provides controls and indicators to change the system status. Provides control of the pedestal hydraulic servo power unit, pedestal braking, the stabilization inputs to the servos, and pedestal position during test. The Versatel lens and film camera controls are also included.

3. Range Acquisition Control-Indicator

   Displays target returns with respect to the transmitter trigger pulse on two dual-gun A-scopes. Provides control of the range tracker and auxtrack, automatic and manual phasing of the transmitter, and allows selection of the operational mode.

4. Oscillator/Pulse Rate Control-Indicator

   Affords control of pulse repetition frequency, pulse width, receiver bandwidth, AGC/MGC, and AFC/MFC of the local oscillators.

5. Radar Monitor Control-Indicator

   Provides control of the transmitted power level and the polarization mode. Enables monitoring of current in the mixer diodes and oscilloscope display of various waveforms throughout the system, such as the envelope of the transmitted pulse, the gated video, range error, and angle error signals.

6. Error/Servo Bandwidth Control-Indicator

   Indicates the computer stabilization source. Displays the servo lag errors and the amount of noise present on the signals, and contains controls to optimize the performance of the servo and error correction systems.

7. Antenna Position Control-Indicator

   Provides control of the designation source and the antenna position.

8. Target Coordinates, Range Rate Control-Indicator

   Displays decimal readout of azimuth, elevation, range, and range rate. Provides selection of the angle reference and control of the range-gate velocity during acquisition.

Most controls are of the pushbutton type with the legends engraved and backlighted for maximum clarity. The controls are normally dimly lit so that titles are visible. The light intensity changes when a particular function is selected. This proven technique significantly reduces the possibility of erroneous selection.

3.9 DIGITAL DATA SUBSYSTEM

The digital data subsystem provides the required buffering to interface the radar data with the ship's central computer. This subsystem also contains the circuits that drive the console displays for decimal readout of range, azimuth, elevation, and range rate based on stabilized-coordinate information supplied from the ship's central computer or unstabilized data derived directly from the radar. The data subsystem is completely transistorized and is contained in three equipment racks, Cabinets 105, 106 and 107. Power supplies for the subsystem are all solid state design and are contained in Cabinets 108 and 110.

Figure 3.9-1 shows a functional block diagram of the digital data subsystem. For descriptive purposes, the subsystem is divided into four sections: computer input equipment, computer output equipment, data subsystem controls, and console display converter. Each of these sections is discussed in some detail in the following paragraphs.

3.9.1 Computer Input Equipment

In order to properly synchronize the radar data, a strobe signal is required from the external ship equipment which is selectable at 10, 20, or 40 pps. Immediately following acceptance of the strobe signal, the data subsystem automatically conditions its output registers. The ambiguous Gray-code words from the pedestal angle encoders are shifted into Cabinet 105 to their respective azimuth and elevation Gray-to-binary converter/ambiguity-correction registers. The azimuth and elevation offset words from the console joystick encoders are shifted into the azimuth and elevation offset Gray-to-binary-converter registers. The three 8-bit A/D converters are activated to quantize the instantaneous values of azimuth servo lag, elevation servo lag and receiver AGC voltage. These three 8-bit words are stored in a shift register in serial form in such a manner that they can be shifted to the computer as a single 24-bit word. Identification bits used for control signals to the computer program are gated into a shift register; these control bits are:

1. On track (to indicate auto track of the angle system)

2. Range verified (to indicate unambiguous range track)

3. Data valid (to indicate operator confidence of track data)

4. Computer designation (to request computer designation)

5. Search scans (3 bits) (to command computer to generate the specified scan)

Five hundred microseconds after receipt of the strobe pulse, the radar data is shifted out (least significant bit first) to the ship's computer buffer system. To accomplish this, 25 shift pulses at a 100-kc rate are accepted on a single line from the ship's Central Data Processor (CDP). The data words described above are shifted out simultaneously on six lines as follows:

Line 1. Azimuth (17 bits binary)

Line 2. Elevation (17 bits binary)

Line 3. Azimuth offset (8 bits binary), Elevation offset (8 bits binary)

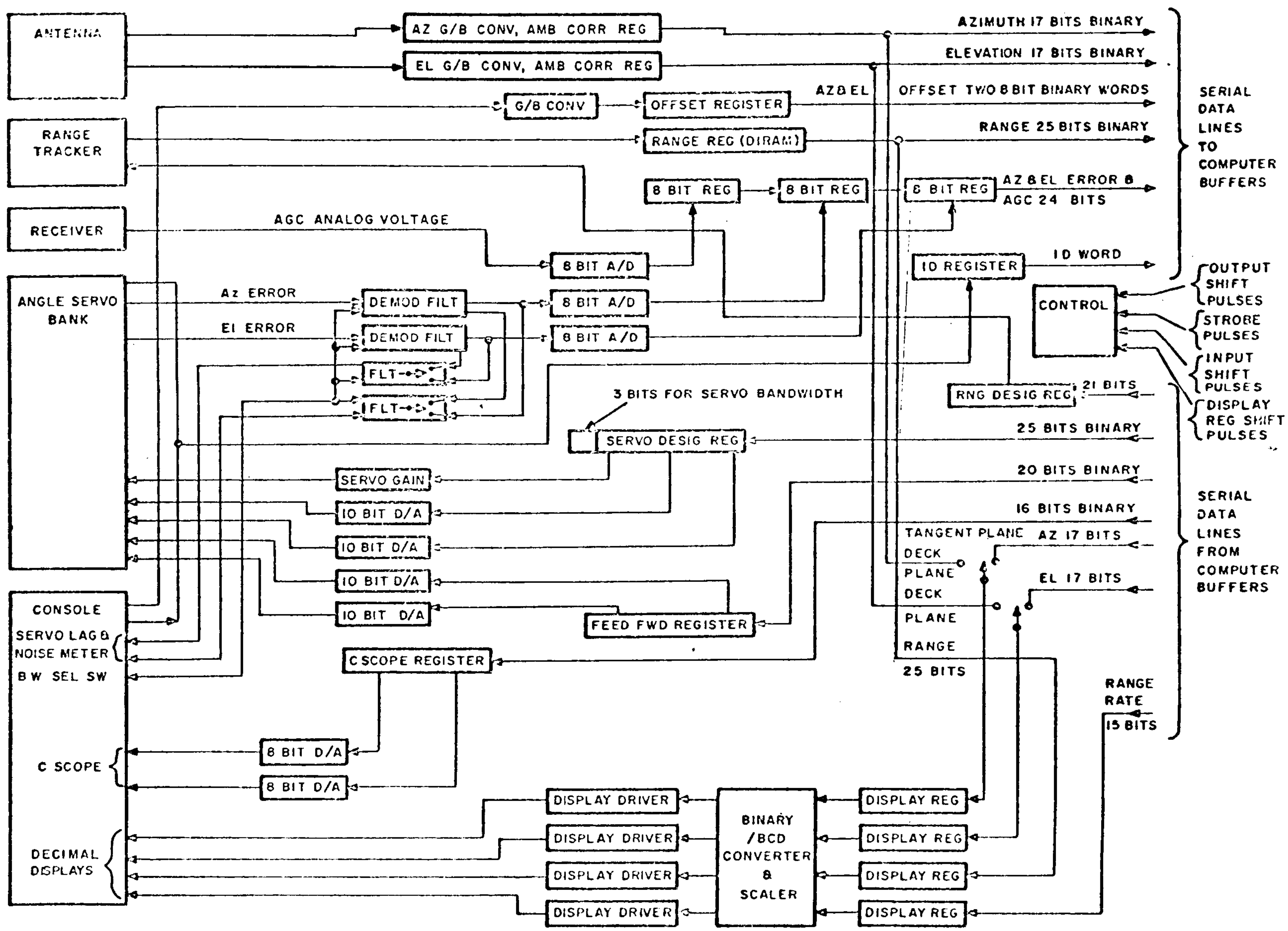


Figure 3.9-1. Digital Data Subsystem Functional Block Diagram

Line 4. Range (25 bits binary)

Line 5. Azimuth servo lag (8 bits binary), Elevation servo lag (8 bits binary), AGC (8 bits binary)

Line 6. Identification word, 10 bits (3 spares)

The range word is shifted directly from the range buffer in the range tracker. The data on the lines is in "nonreturn-to-zero" form, and is "aligned" at the least significant bit.

The digital data subsystem also contains the electronic circuitry to drive the radar console meters to display angle servo lag and noise. The error signals, in addition to being quantized in the digital circuits, are separated into low- and high-frequency components by filters (ERROR CORRECTION BW switch controls the filter bandwidth). These filtered signals, representing lag and noise respectively, are then rectified and displayed in analog form on LAG and NOISE meters at the console.

The azimuth and elevation Gray-to-binary converter/ambiguity-correction registers and the azimuth and elevation offset Gray-to-binary converter registers are improved from those previously used in AN/FPS-16 radars. Previously, the gray words were shifted directly into the register, then circulated through the Gray-to-binary conversion, and then, for the azimuth and elevation words, recirculated once more for ambiguity correction. For the present design, this section of the data subsystem has been redesigned with a resulting saving in hardware and an increase in reliability. In this system as the data word (azimuth, elevation, or offset) is being shifted into data handling, the Gray-to-binary conversion is performed. At the same time, a parity count of the number of "ones" in the resulting binary word is obtained. Gray-to-binary conversion, least significant bit first, requires a parity count since odd parity indicates that the resulting binary word is the complement of the true result. Complementing, where required, is performed during serial shift out to the computer input by selecting the proper output gate from each register to provide true data. For the azimuth and elevation words, the optical and mechanical portions are converted from Gray to binary independently during shift in from the pedestal, each with its respective parity count. A half adder is inserted between the two sections of each of these registers in such a manner that if the need exists for ambiguity correction, it is also performed during shift out to the computer.

3.9.2 Computer Output Equipment

At some time after the radar data has been read into the computer (possibly 10 milliseconds later), the computer provides data to the radar to close the angle servo loop in the designation mode, to designate the range tracking unit, to provide ship's velocity data to stabilize the antenna in acquisition and track modes, provide C-scope deflection to show instantaneous antenna scan position with respect to the designation point and to drive the radar console decimal displays.

A twenty-one bit range designation word is shifted directly to the range system to designate the range tracking system. The computer closes the angle designation loop by providing a 25-bit word to the servo designation register. This word contains a 10-bit azimuth error word, a 10-bit elevation error word, two scale bits to control the servo gain and three spare bits for possible future use for bandwidth control. In a similar manner, a 20-bit word is shifted from the computer into the feed forward register. This word contains a 10-bit azimuth velocity word and a 10-bit elevation velocity word for stabilization of the antenna from ship's motion. Four 10-bit digital-to-analog converters have been employed to convert the error and velocity words to analog voltages for use by the servo system.

The computer provides a 16-bit word to the C-scope register, containing two 8-bit words representing instantaneous azimuth and elevation deviation from the designate point. Two 8-bit digital-to-analog converters have been employed to convert these words to analog signals to drive the scope.

Under control of a separate shift pulse line, 17-bit azimuth, 17-bit elevation, and 15-bit range-rate words are shifted from the computer to the display section of the data subsystem (once per second) to drive the decimal displays on the console. Each time this data is transferred from the computer a sample of range is obtained directly from the range subsystem for use by the displays.

3.9.3 Data Subsystem Controls

The data subsystem controls allow one of two modes of operation: either computer or local mode.

In the computer mode, the radar is actually receiving the radar strobe, display information and possibly designation information from, and supplying its output data to, the ship's Central Data Processor.

Under this mode, the data subsystem accepts the radar strobe from the computer at 10, 20, or 40 pps, and generates a strobe for the pedestal encoders, range subsystem, joystick inputs and ID inputs. The data subsystem controls then generate a delay to allow for settling of pedestal encoders, followed by a set of pulses to shift the azimuth and elevation Gray data from the pedestal to the data subsystem. In addition the controls generate all the required clear and control pulses for Gray-to-binary conversion, and all the required time slot pulses for the analog-to-digital converters. The data controls then must accept the computer shift pulses to shift the radar output data into the computer. The control logic also receives the display shift pulses for transferring display information (once per second), and computer shift pulses for transferring designation information.

The data subsystem has been designed so that it can operate independent of the ship's CDP in the local mode. In this mode, the data subsystem, utilizing internal equipment, generates its own radar strobe at 29 pps in place of that provided by the computer. In addition, for local mode, the data subsystem provides an internal 1.7-pps pulse to operate the console displays, and generates a set of 25 shift pulses to replace the computer input pulses. With the above exceptions, the control logic operates the same as in the computer mode.

3.9.4 Console Display Converter

The console display converter has been designed to accept binary data from either the ship's CDP (when stabilized data is required) or directly from the radar (when deck-plane-referenced data is acceptable or if the computer is not available to the radar), multiply it by the proper scale factor, convert it to binary-coded-decimal form and drive the console displays. The resulting displays are as follows:

1. RANGE - YARDS (Eight-place decimal)

2. AZIMUTH - MILS (Five-place decimal, least significant place is tenths)

3. ELEVATION - MILS (Sign and four-place decimal, least significant place is tenths)

4. RANGE RATE - YARDS/SEC (Sign and six-place decimal)

The equipment consists of a set of storage registers, a data register, multiplier register, partial-product register, a two-bit adder, control logic, and display driving equipment.

The four storage registers are designed to accept range information from the range subsystem, azimuth and elevation from either the computer or the radar, and range rate from the computer. Range rate data will only be available under the computer mode of operation.

Figure 3.9-2 is a functional block diagram of the console display converter. The controls can conveniently be separated into two sections. The display system controls receive the start signal from the storage buffers and control shifting of the data to the data register, starting scaling and conversion, and transferring the data to the display nests. The conversion control handles the scaling and binary/binary-coded-decimal conversion.

A typical display cycle starts when the "range ready" signal (indicating that a new range word is in the range storage buffer) is received. This signal sets the range display control, allowing the pilot bit to be set in the correct position in the data register, and enabling shift of data from the range storage buffer. The data is then shifted into the data register. When the pilot bit gets to the sensing circuit in system control, the shifting controls are reset and a start conversion signal is sent to conversion control. Conversion control produces a reset signal for the pilot bit sensing; controls scaling and BCD conversion and sends a "conversion complete" signal back to display control. Display control strobes the contents of the partial-product register into the display nest to drive the lamps for the range word, and then provides a trigger which sets the azimuth display control and resets the range display control. The process of setting the pilot bit in the proper position, shifting the word from the proper storage register to the data register, scaling, converting, and strobing into the azimuth display drivers is performed in the same manner as for range

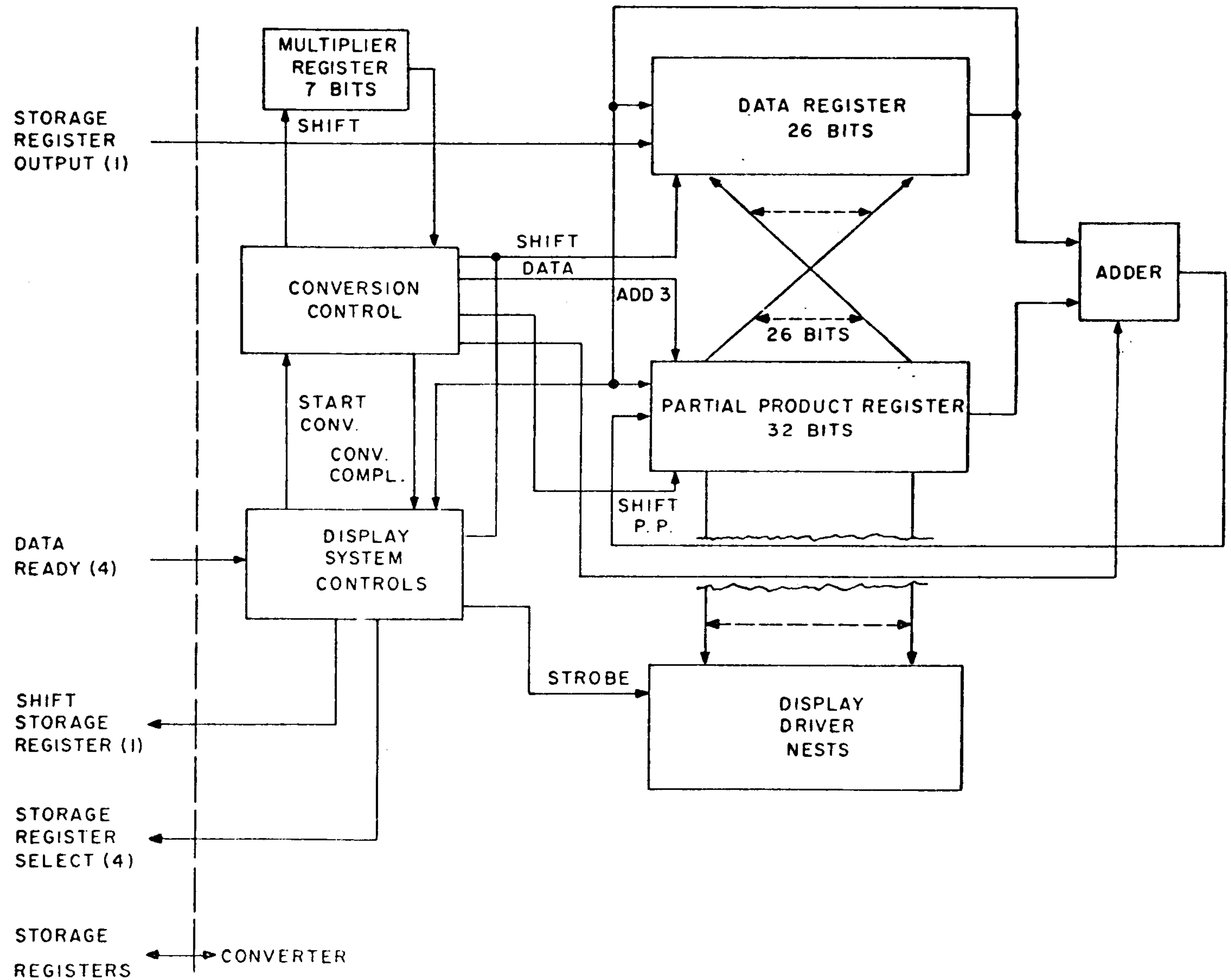


Figure 3.9-2. Console Display Converter Block Diagram

data. Similarly, the elevation and range rate information are processed, except that following display of range rate, a reset signal is generated instead of a trigger to the display control flip-flops. This signal resets the storage buffers, preparing them to receive new data from the radar and/or computer for the next display cycle.

If azimuth, elevation, or range rate information is not available from its storage register, the partial-product register will be reset and then displayed resulting in an all zero display for unavailable data.

Logic is also included to drive the lamps for the positive and negative signs for range rate information, and to insert a negative sign in the elevation display when required.

Upon receiving the "start conversion" signal from display system controls, conversion control initializes itself, resetting the partial-product register and setting the scale factor into the multiplier register. Scaling is begun by examining the least significant bit of the multiplier register. If it is a one, the contents of both the data and partial-product registers are shifted through the adder and the result shifted into the partial-product register, while the data register is recirculated. Since the data register is 26 bits and the partial-product register is 32 bits, six extra shift pulses trigger the partial product, plus one extra pulse to shift off the least significant bit and shift the multiplier register one place to the right in preparation for processing the next multiplier bit. If the multiplier bit is a zero, the partial-product and multiplier registers are shifted one place and the next bit examined. When the last multiplier bit is being processed, the data register recirculation is inhibited so that the final product is formed in the partial-product register with the data register cleared.

The first step of the binary/binary-coded-decimal conversion is a parallel transfer from partial-product to data register, reversing the order of the bits. Multiplication requires LSB first, but conversion requires MSB first. The partial-product register consists of eight decades of four bits each to form 32 bits. To perform the conversion each decade is examined and a binary three (0011) is added to all decades containing five or greater. The contents are then shifted once to the right and the next bit from the data register shifted in. The process of alternately examining the decades and shifting is continued until the entire data register has been cleared (26 shifts). The resulting BCD information will be formed in the partial-product register ready for strobing into the proper display drivers. Conversion control then sends the conversion complete signal to display system controls.

The incorporation of this console display converter into the radar data subsystem is significant for two reasons. First of all, it removes the time consuming binary/binary-coded-decimal conversion from the computer, and secondly, it provides a method of having console displays operating without the necessity of being permanently tied to the ship's CDP in the event of a computer failure, or if the computer is occupied with an off-line function.

3.10 SUPPLEMENTARY EQUIPMENTS

This section briefly discusses those portions of the radar system that support or supplement the primary system functions. Some of these equipments are required for system operation while the others are used primarily for monitoring, testing, or calibration.

3.10.1 Video and Error Distribution Section

The video and error distribution section (Cabinet 114) consists of one video distribution unit and one error distribution unit that provide amplification, isolation, and distribution of the video and error signals throughout the system and for external use.

3.10.2 Power Supply and Distribution Equipment

The low-voltage power supplies include the amplifiers, preamplifiers, drivers, and dividers necessary to supply the low voltages required by the system. These power supplies are housed in various cabinets, as follows: Cabinet 101 contains the power supply controls; digital data subsystem power supplies are located in Cabinet 108; pedestal power supplies, in Cabinets 114, 115 and 117; angle servo supplies, in Cabinets 116 and 117; and range servo power supplies are located in Cabinets 103 and 121. Cabinets 112 and 113 are used for cable termination and signal distribution among the subsystems.

3.10.3 Designation Synchros

Three sets of local-designation synchros located in Cabinet 103 can be manually set and locked. The antenna will automatically be positioned by these synchro inputs when one of three test positions (Boresight tower, RF Head, or Test) is selected at the console.

3.10.4 Running Time Meters

Time meters located in Cabinet 104 display the total running time of various components. Meters are included for radar standby, radar operate, hydraulic servo pump, hydraulic bearing pump, angle servo filaments, range section filaments, receiver filaments, angle servo power supply, range power supply, digital power supply and pedestal (receiver) power supply.

3.10.5 Failure Indicator

The failure indicator panel is located in Cabinet 104. This arrangement monitors the safe operating limit of various components. When the safe limit is exceeded, a buzzer sounds and a light is illuminated. The operator can elect to either stop radar operation and investigate the trouble, or he can turn the buzzer off and continue to operate at the risk of damaging the component. The items that are monitored include RF head overheat, pedestal oil pressure, radar air conditioner temperature, transmitter conditions (include wave guide pressure, air flow and magnetron current), hydraulic bearing pump, hydraulic servo pump high reservoir temp and low system pressure or high filter pressure, angle servo power supply, range power supply, digital power supply and pedestal receiver power supply.

3.10.6 Noise Figure and Power Monitor

This unit is located in Cabinet 104. Circuitry and controls are provided to measure the radar receiver noise figure and to measure the radar transmitter power output.

3.10.7 Data Recorder

A four-channel analog recorder is located in Cabinet 102. An instrumentation patch panel located in Cabinet 103 facilitates the connection of various functions into the recorder.

A contract change provided a modification kit to enable recording of real-time codes (IRIG-C).

Section 4

ACCEPTANCE TESTING PROGRAM

The prime objective of the acceptance testing program was to demonstrate that the performance of the ASIR system met the requirements of NASA Specification GSFC-OIS-1, Revision B, dated July 10, 1964. To fulfill this objective, an acceptance test procedure was prepared by RCA and approved by the Goddard Space Flight Center. This test procedure (TS-1-8337073) defined the subsystem and system tests that were performed at the Moorestown plant on each of the three ASIR systems.

Detailed test procedures were prepared for each of the tests outlined in the acceptance test procedure. These subsidiary test procedures were in sufficient detail to permit factory test personnel to perform the tests and inspection personnel, both Government and RCA, to follow and witness each test. The witnessed data sheets form the basis for the test results reported in this section.

4.1 TRANSMITTER AND MODULATOR TESTS

4.1.1 Transmitter Power Output

The performance specification requires that the transmitter shall attain a peak power output of 1 megawatt over the frequency range of 5450 to 5825 Mc. To measure this, the test specification requires that each transmitter be tested at three frequencies as shown in Table 4.1-1.

TABLE 4.1-1

FREQUENCIES AND PULSE PARAMETERS USED IN POWER OUTPUT TESTS

Frequency (Mc)	PRF (sec^{-1})	Nominal Pulse Width (Microseconds)
5450	160	0.25
5450	640	1.0
5600	160	0.5
5600	640	1.0
5825	160	0.25
5825	640	1.0

To measure the power, the transmitter was made to feed a calorimeter load which was water cooled so that the average power dissipated could be measured from the product of the flow rate and temperature rise. While the test was in progress, an oscilloscope was used to measure the PRF and the width of the pulses (between the 3-db-down-from-peak points as established by means of a calibrated 3-db attenuator). From the measured PRF and pulse width, the duty cycle was obtained so that the average power readings, as measured by the calorimeter load, could be converted to peak power readings.

All three transmitters (i.e., one for each radar system) were tested successfully in this manner. The lowest peak power reading obtained (for any combination of transmitter, PRF, and pulse width) was 1.014 megawatts; the highest was 1.272 megawatts.

It should be pointed out that these peak power readings represent power at the magnetron RF window, since the computations included the known 1.2-db insertion loss from the magnetron window to the calorimeter water load. This insertion loss is represented by the waveguide run, the variable attenuator, and the isolator.

4.1.2 Power Monitor Test

As part of the transmitter power output measurement, the operation of the Power Monitor (Unit A3 in Monitor Group Cabinet 104) was checked. This device employs a bolometer (thermistor) which is exposed to the transmitter RF and which also constitutes one element in a bridge circuit fed by a 10-Kc oscillator. The bridge-circuit-and-oscillator combination are arranged to be self-balancing so that when waveguide RF power heats the thermistor (thus changing its resistance and unbalancing the bridge) the unbalance voltage controls the 10-Kc oscillator feedback to reduce the output of the oscillator (and consequently its heating effect on the thermistor) until balance is restored. A two-stage amplifier and rectifier circuit are coupled to the 10-Kc oscillator and arranged so that an increase in transmitter output (and correspondingly a decrease in 10-Kc oscillator output) will produce an increase in the reading of a d-c meter.

Since the bolometer resistance changes represent average power, the d-c meter readings also represent average power. The ratio between average transmitter power output and meter readings is about 100 to 1, but this ratio is not constant because the response of the monitor circuit is not perfectly linear and because the system is affected by differences in transmitter frequency and duty cycle. In the tests the ratio (between measured transmitter average power output and monitor meter reading) varied between 79 to 1 and 129 to 1 for various combinations of transmitter, PRF, and pulse width.

4.1.3 RF Pulse Width

The performance specification requires that the transmitter shall be capable of transmitting pulses with durations selectable at 0.25 ± 0.05 microseconds, 0.5 ± 0.05 microseconds, and 1.0 ± 0.1 microseconds.

This test was performed by making measurements of the actual RF pulse using the detector in the system wavemeter and measuring the width of the resulting detected video on an oscilloscope with a calibrated (0.1 microsecond per cm) horizontal sweep.

The pulses were measured between points on the leading and trailing edges of each pulse. These points were 3 db down from the peak values and were established on the oscilloscope beforehand through the use of a 3-db calibrated attenuator inserted momentarily in the signal line.

All three transmitters met the specification requirements as shown in Table 4.1-2.

TABLE 4.1-2

TRANSMITTER PULSE WIDTH MEASUREMENT RESULTS

RF Freq. (Mc)	PRF (pps)	Required Pulse Width (usec)	Measured Pulse Width (Microseconds) System No. 1 (Serial No. 47)	System No. 2 (Serial No. 48)	System No. 3 (Serial No. 49)
5650	640	0.25±0.05	0.22	0.26	0.26
5650	640	0.5 ±0.05	0.50	0.52	0.54
5650	640	1.0 ±0.1	1.0	0.96	1.04

4.1.4 Pulse Coding

The transmitter is required to be able to transmit a group of at least 3 pulses 0.25 ± 0.05 microseconds in duration with a minimum spacing of 1.0 microsecond or less from leading edge to leading edge to leading edge. Moreover the difference in peak power between any 2 pulses in the 3-pulse group should not exceed 1 db.

For this test, a pulse width of 0.25 microseconds and a PRF of 160 was set at the console. The beacon coding generator was adjusted (by the delay line adjustments in the system) to provide a spacing between pulses in a group of not less than 1 microsecond. This spacing was measured from the leading edge of one pulse (at a point 70% down from peak) to the identical position on the leading edge of the succeeding pulse.

The test was performed without any difficulty and all readings were within the specification limits. Table 4.1-3 summarizes the results for all three transmitters.

TABLE 4.1-3

PULSE CODING TEST RESULTS
(Group of 3 Pulses)

Pulse Parameters	Spec limit	System No. 1	System No. 2	System No. 3
Peak Power Difference (db)	1.0 max.	1.0	1.0	1.0
Pulse Spacing (usec)	1.0 min.	1.2	1.0	1.3
Width, Pulse No. 1 (usec)	0.25±0.05	0.22	0.25	0.25
Width, Pulse No. 2 (usec)	0.25±0.05	0.22	0.24	0.24
Width, Pulse No. 3 (usec)	0.25±0.05	0.22	0.26	0.24

4.1.5 Pulse Spectrum

The spectrum was measured with the transmitter feeding a dummy load and operating at 5600 Mc, 0.25 usec pulse width, and 640 PRF. The requirement was that the nearest side lobe on either side of the main lobe (frequency domain) should be down at least 8 db below the main lobe.

A Polarad Spectrum Analyzer was used. It was connected to the RF output of the transmitter at terminal J14003 (which connects, through directional couplers, to the waveguide).

The test method (RCA TM-130-8337073) purposely detailed the adjustment and operation of the spectrum analyzer in order to anticipate and correct potential sources of error as follows:

a. Operation with image. The test method ensured that the Polarad amplitude-vs-frequency display showed the true signal and not the image (separated from the true signal by twice the 160-Mc center IF frequency of the Polarad equipment).

b. Limiting. The analyzer attenuator controls were adjusted so that the main pulse on the amplitude-vs-frequency display was not being limited by amplifier overload.

c. Amplitude Calibration. Since the requirement is that side lobes in the Polarad amplitude-vs-frequency display shall be 8 db down from the amplitude of the main frequency, the 8-db down point was calibrated by inserting an 8-db antennuator in the signal line momentarily and noting the reduction in the amplitude of the main lobe on the display.

Results of the test were quite satisfactory. The three transmitters showed frequency sidelobes on the Polarad panoramic display which were down from the main lobe by 14.7, 15, and 16.5 db respectively.

4.1.6 VSWR Measurement

The VSWR in the waveguide between transmitter and antenna pedestal was measured using the radar's own VSWR Monitor. This monitor is part of what is called the "interface microwave components" and is connected to the waveguide via a 40-db dual directional coupler which samples the forward and reflected RF energy. A level-set control provides required attenuation of the forward power sample. A switch on the VSWR monitor allows selection of either the forward or reflected power. The selected sample is applied to a thermistor which makes up one leg of a self-balancing bridge circuit which is similar in principle to the Power Monitor described in Paragraph 4.1.2 above.

Before the VSWR Monitor was used, it was calibrated by a reciprocity method in which RF energy was made to pass through the monitor's 40-db dual directional coupler (to a matched load) first in one direction and then in the other. The source of the RF energy was the transmitter whose level was set at amplitudes established by means of a Hewlett Packard HP 434A Power Calorimeter Meter.

After the VSWR Monitor was thus calibrated, it was re-installed properly in the radar system. With the transmitter feeding the antenna, the VSWR readings in Table 4.1-4 were obtained. Data for all three systems are given.

TABLE 4.1-4

VSWR TEST RESULTS

RF Freq. (Mc)	VSWR System No. 1	VSWR System No. 2	VSWR System No. 3
5450	1.45:1	1.40:1	1.0:1
5600	1.27:1	1.59:1	1.12:1
5825	1.28:1	1.75:1	1.10:1

4.1.7 Test of Transmitter Controls and Indicators

In each system the console operating controls associated with the transmitter were exercised and checked. Thus, for example, the transmitter was turned on and made to radiate, and the PERCENT REL PWR ADJUST control was cycled from full CCW to full CW. During this cycle the power output changed from zero to 100 percent of full power as indicated by the PERCENT REL PWR meter on the console.

All controls operated in accordance with the performance specification.

4.2 ANTENNA TESTS

Acceptance testing of the antenna assembly consisted of gain measurements and antenna-radiation-pattern recordings to determine beamwidth, depth of null and sidelobe levels. The antenna gain was measured at each of three frequencies (namely, 5400, 5600, and 5900 Mc). Vertical and horizontal cuts of the sum and error patterns were recorded at the same frequencies for both switching positions of the polarization programmers.

4.2.1 Antenna Gain

The antenna gain measurements were made utilizing a substitution technique. With a standard horn, of known gain, receiving energy from a fixed signal source, the output of a test receiver was used to establish a reference point. The antenna was then substituted for the horn. A calibrated attenuator inserted in the receive channel was adjusted until the receiver output returned to the reference point. The attenuator setting determined the amount by which the gain of the antenna exceeded that of the standard horn. The antenna gain was measured as follows:

Frequency (Mc)	Antenna Gain (db)
5400	46.3
5600	47.6
5900	46.05

4.2.2 Antenna Patterns

The antenna patterns were recorded on the RCA Moorestown test range. The test range includes a 200-foot tower to mount a signal source which can radiate either vertically- or horizontally-polarized energy and a special test pedestal located approximately 5000 feet from the signal tower to obtain far-field data. The test pedestal rotates in the horizontal plane so that with the use of a test receiver and a synchronized and calibrated pen/paper recorder, antenna patterns are recorded. The test pedestal has the flexibility of rotating the antenna assembly 90 degrees about its boresight axis which allows recording of horizontal as well as vertical cuts through the radiation pattern with only horizontal motion of the pedestal. This arrangement eliminates possible multipath effects.

Numerous radiation patterns were recorded; horizontal and vertical cuts were taken in each of the four channels (linear reference, circular reference, azimuth and elevation error), for both polarizations, at three frequencies (nominally, high, low, and mid-band), and for each of the three systems.

The antenna beamwidth as determined from the reference-channel patterns was found to vary from 0.66 to 0.797 degrees. The depth of null in all the error patterns exceeded the specified 35-db-down requirement.

The performance specification requires that the maximum power density of the reference- and error-channel sidelobes should be 18 db down from that of the main lobe at all operational frequencies. The recorded patterns revealed that most of the sidelobes were below the specified value; however, a few sidelobes were measured at only 16.5 db down. Since the antenna gain exceeds the 46-db requirement, the sidelobe levels do not materially affect system performance and a waiver of this requirement was requested. Contract Change Order Nos. 8, 17, and 18, dated 19 July, 31 August, and 13 October 1965 respectively, approved the higher sidelobe levels for each of the three systems.

4.3 RECEIVER TESTS

4.3.1 Receiver Noise Figure Measurement

Noise figure was measured by the "Y-factor" method which has become an accepted standard technique*. In applying this technique the noise output of the receiver (30-Mc IF) was measured with and without a noise input as furnished by a calibrated argon-tube noise generator. With the noise generator off and the radar receiver input simply terminated in a matched impedance at the standard temperature ($T_o = 200^\circ K$), a reference output was obtained; this represented standard temperature (T_o) thermal input noise plus noise contributed by the receiver. Then the argon-tube noise generator was turned on. The increase in receiver output noise was measured by adding attenuation until the output noise level was restored to its original (noise-generator-off) level. The attenuation required is, by definition, the "Y factor" expressed in db. The noise figure of the receiver could then be calculated from:

$$F_{db} = 10 \log \left[\frac{T_2}{T_o} - 1 \right] - 10 \log (Y-1) + 3$$

where T_2 = effective temperature of the noise generator when fired.

$T_o = 290^\circ K$

Y = ratio of the power output of the receiver when its input is terminated with its characteristic impedance at T_o to the power output when the input is terminated with its characteristic impedance at T_2.

*M. Skolnik: "Introduction to Radar Systems", McGraw Hill, 1962, pp 364-365.

In making this measurement, the receiver AGC was disabled, and the manual gain control voltage was applied to the AGC bus so that the presence or absence of the noise generator input had no effect on receiver gain.

The radar receiver consists of three separate channels (reference, azimuth, and elevation), and each channel employs its own mixer, IF preamplifier, and IF main amplifier. Consequently the noise figure of each channel was measured separately. Also each channel was measured at three frequencies across the operating band. Table 4.3-1 gives results for all three radar systems. All readings are within the 11-db specification limit.

TABLE 4.3-1

MEASURED RECEIVER NOISE FIGURE IN DB

System No.	Receiver Channel	L.O. Frequency 5870 Mc	5630 Mc	5430 Mc
1	Reference	10.8	10.9	9.8
1	Azimuth	10.2	10.8	10.8
1	Elevation	10.9	10.97	10.9
2	Reference	10.9	10.4	10.5
2	Azimuth	10.9	11.0	10.7
2	Elevation	10.7	10.7	10.5
3	Reference	9.0	8.7	10.0
3	Azimuth	8.6	8.7	8.5
3	Elevation	10.0	9.0	8.6

4.3.2 Noise Figure Monitor Test

The radar contains a built-in provision for checking receiver noise figure. The operation of this built-in system was tested as part of the receiver test.

The purpose of the noise-figure monitor system is to allow an operator to make periodic checks of receiver noise figure as part of a preventive maintenance routine. Consequently the design of the system emphasizes precision and simplicity more than absolute accuracy.

The built-in noise-figure checking system permits measurement of the noise figure of each receiver channel (reference, azimuth and elevation) individually. Each channel thus measured consists of the input waveguide and tuner, the mixer, the IF preamp, and the main IF amplifier. Choice of a channel is made in the ungated IF amplifier. This amplifier is fed by the main amplifier in each channel but has means for selecting the output of any one of the three channels.

The actual noise-figure measurement system is as follows. The selected-channel IF input feeds a thermistor which is also part of a bridge circuit operating at 10 Kc. Any IF signal or noise applied to the thermistor element will change its resistance due to local heating, and the 10-Kc bridge circuit voltage must be adjusted to compensate. A meter amplifier is coupled to 10-Kc circuit so that the meter gives a measure of IF signal and/or noise power.

The monitor is used in conjunction with an argon-tube noise source (15 db above thermal) which can be coupled to the waveguides at the front end of each receiver channel. Measurement of the noise figure of individual channel consists of measurement of receiver noise with and without the argon-tube noise source fired. This method is analogous to the Y-factor method described above.

Allowed limits for the noise figure monitor readings were 5 to 13 db. Actual readings are listed in Table 4.3-2.

4.3.3 Skin AFC Tuning Range

The receiver local oscillator is required to tune automatically the receiver to the transmitting signal over a range of ± 12 Mc from the initial receiver frequency. This was checked at 6 different frequencies for each radar. A PRF of 160 pps and a pulse width of 1.0 usec was used. Results are listed in Table 4.3-3. The deviation in the 30-Mc IF after lock-on to the target echo signal is shown. (A limit of ± 400 Kc is allowed in the system design.)

4.3.4 Voltage-Sensitive Attenuator Test

The performance specification for the radar requires that if the radar is in the skin-track mode with the receiver local oscillator locked to the sampled transmitter frequency (to provide a 30-Mc IF), the local oscillator must remain locked as the transmitter output is reduced from full power to 5% of full power. This requirement was met in tests of each of the three radar systems.

TABLE 4.3-2

NOISE FIGURE MONITOR TEST RESULTS*

System No.	Receiver Channel	L.O. Frequency 5870 Mc	5630 Mc	5430 Mc
1	Reference	6.9 db	7.8 db	9.2 db
1	Azimuth	7.9 db	8.3 db	8.7 db
1	Elevation	9.0 db	8.5 db	9.0 db
2	Reference	8.7 db	8.7 db	8.5 db
2	Azimuth	9.2 db	9.3 db	9.8 db
2	Elevation	8.2 db	8.0 db	8.8 db
3	Reference	8.4 db	7.9 db	9.8 db
3	Azimuth	8.3 db	7.5 db	8.1 db
3	Elevation	8.6 db	7.5 db	8.2 db

*A factor of 3 db must be added to the indicated values. The noise figure monitor is calibrated for operation with parametric amplifiers in the receivers.

TABLE 4.3-3

SKIN AFC TUNING RANGE TEST RESULTS

XMTR Freq.	IF Frequency Deviation After Lock-On (±400 Kc Allowed). System No. 1	System No. 2	System No. 3
5440	100 Kc	100 Kc	50 Kc
5460	100 Kc	150 Kc	200 Kc
5590	100 Kc	100 Kc	200 Kc
5610	100 Kc	100 Kc	150 Kc
5815	200 Kc	150 Kc	50 Kc
5835	300 Kc	100 Kc	200 Kc

In performing the test, the transmitter was adjusted to a PRF of 640 and a pulse width of 1 microsecond. The antenna was allowed to radiate. With the receiver initially off frequency the "LOCAL OSCILLATOR-SKIN-AFC-XMTR" pushbutton was depressed. Lock-on of the local oscillator was noted by two phenomena: (1) the AFC DEVIATION meter exhibited as initial sweeping action followed by a constant indication, and (2) video, sampled by an oscilloscope at the input of the AFC unit, rose to a peak and remained there.

With lock-on thus established, the transmitter power was reduced (by manual control of the console) from 100% of full power to 5% and return. At no time did the skin-AFC go out of lock-on.

This test was performed at RF frequencies of 5450, 5600, and 5825 Mc for all three systems.

4.3.5 Beacon AFC Tuning Range

The beacon local oscillator in the receiver is equipped with an automatic frequency control feature so that the receiver will "lock-on" to the frequency of an incoming beacon signal from initial frequency settings as much as 12 Mc away, depending on the S/N ratio of the beacon signal.

For this test the beacon signal was simulated by a Hewlett Packard 618B Signal Generator coupled through calibrated attenuators to the reference waveguide. Initially the level of this signal generator was adjusted so that with 60 db of calibrated attenuation between the generator and reference waveguide, the signal output of the receiver was exactly equal to noise (zero db S/N). Once so adjusted, S/N ratios of 6, 25, and 60 db could be attained simply by reducing the settings of the calibrated attenuator (i.e., reducing the amount of attenuation) by 6, 25, and 60 db.

The HP 618B Signal Generator was pulsed (at 160 pps) with a pulse width of 0.75 usec, and the output of the receiver IF was observed on Polarad Spectrum Analyzer whose frequency sweep was centered at the nominal 30-Mc IF frequency. A Hewlett Packard 608C Signal Generator operating at 30-Mc CW was used to provide a 30-Mc "marker" on the Polarad frequency sweep (amplitude-vs-frequency) display.

The conduct of the test was as follows. The frequency of the HP 618B beacon simulator was displaced from the receiver frequency by the specified amount (6 Mc for 6 db beacon-signal-to-noise ratio, and 12 Mc for 25 and 60 db beacon-signal-to-noise ratio). Then the receiver beacon AFC junction was activated (by depressing the "Local Oscillator Beacon AFC" pushbutton. When this button was depressed, a stop watch was also started, and the elapsed time was measured until the simulated beacon signal came into view on the Polarad panoramic display of the IF and settled near the nominal 30 Mc. When the output had thus settled, its deviation from exactly 30 Mc was measured to verify that the deviation was less than the allowed 0.5 Mc.

Results of the test with System No. 1 (Serial No. 47) are listed in Table 4.3-4. The other two systems gave results which are equal or better. Column headings in the table are briefly explained here as follows.

TABLE 4.3-4

BEACON AFC TUNING RANGE
(System No. 1)

Nominal RF Freq.	Nominal L.O. Freq.	S/N	RF Freq. Set to:	Time To Lock On	IF Freq. Deviation
5890 Mc	5920 Mc	6 db	-6 Mc	3 sec	100 kc
"	"	6 db	+6 Mc	3 sec	100 kc
"	"	25 db	-12 Mc	3 sec	100 kc
"	"	25 db	+12 Mc	3 sec	100 kc
"	"	60 db	-12 Mc	3 sec	100 kc
"	"	60 db	+12 Mc	3 sec	100 kc
5600 Mc	5630 Mc	6 db	-6 Mc	3 sec	200 kc
"	"	6 db	+6 Mc	3 sec	200 kc
"	"	25 db	-12 Mc	3 sec	200 kc
"	"	25 db	+12 Mc	3 sec	200 kc
"	"	60 db	-12 Mc	3 sec	200 kc
"	"	60 db	+12 Mc	3 sec	200 kc
5410 Mc	5440 Mc	6 db	-6 Mc	3 sec	200 kc
"	"	6 db	+6 Mc	3 sec	200 kc
"	"	25 db	-12 Mc	3 sec	150 kc
"	"	25 db	+12 Mc	3 sec	150 kc
"	"	60 db	-12 Mc	3 sec	100 kc
"	"	60 db	+12 Mc	3 sec	100 kc
	Allowed Limits			10 seconds max.	30.0 Mc +0.5 Mc

The first two columns, "Nominal RF Frequency" and "Nominal L.O. Frequency" are settings at the beginning of each individual test. Thus in the first test (first line of Table), the beacon simulator (HP 618B as described above) was set to 5890 Mc, and the receiver local oscillator was tuned to 5920 Mc to give the nominal 30-Mc output. This was observed on the Polarad analyzer display at the beginning of the test.

The third column of the table lists the ratio of beacon signal to noise as set for each individual test. These ratios were set by means of the calibrated attenuators as described above.

The fourth column of Table 4.3-4 refers to the beacon frequency offset which was deliberately introduced for each individual test. Thus in the first test (first line of the table) the beacon signal frequency was reduced 6 Mc from its initial 5890 Mc. This frequency change was introduced of course, with the receiver AFC junction not activated.

The fifth column, "Time to Lock-on", lists the time in seconds for the receiver AFC to lock on to the displaced beacon signal frequency after the AFC was activated. This time was measured with a stop watch as explained above.

The sixth column of the table lists, for each individual test, the deviation from 30 Mc which the IF output exhibited once it had locked on to the simulated beacon signal.

4.3.6 Beacon Hold-In with Signal Loss

The receiver beacon AFC is designed so that in the event that the beacon signal is interrupted, the beacon local oscillator will not drift from its existing frequency by more than 12 Mc in 60 seconds at a PRF of 160 pps.

This was tested at three different frequencies. Results for all three radars are given in Table 4.3-5.

TABLE 4.3-5

BEACON L.O. HOLD-IN WITH SIGNAL LOSS

Initial	Drift Over Period of 60 Seconds, No Beacon Signal		
L.O. Freq.	System No. 1	System No. 2	System No. 3
5920	+4 Mc	+7.0 Mc	+4.0 Mc
5630	+7 Mc	-9.0 Mc	-1.0 Mc
5440	+3 Mc	-1.0 Mc	+7.0 Mc

4.3.7 Dynamic Range Test

The dynamic-range performance of the receiver was demonstrated by simulating an incoming RF off-axis signal and by showing that the resulting angle servo error input remained relatively constant despite wide variations in signal intensity.

The specified performance is as follows. For simulated RF input signals at 5600 Mc, 640 pps, 1 usec pulse width, and 1 angular mil off axis in azimuth and elevation, the relation between input signal intensity and angle error signal voltage should be such that:

(a) Variations in input signal intensity from 10 db S/N to 50 db S/N should produce no more than 4 db total change in the error voltage furnished to the angle servo amplifiers.

(b) Further variations in input signal intensity from 60 db S/N to 73 db S/N should produce changes in the error voltage of no more than $\pm$ 3 db from a reference voltage established above as the mid-reading level of the 10 db to 50 db range.

For this test a Hewlett Packard 618 Signal Generator served as the 5600-Mc RF signal source. Its output was fed to three input (waveguide) channels simultaneously: the linear reference channel, the azimuth error channel, and the elevation error channel. Individual attenuators and phase adjustments in each channel permitted simulation of a signal 1 mil off axis.

The beacon local oscillator was tuned to 5630 Mc so that the nominal 30-Mc IF resulted. This also produced an error signal (square wave) at the outputs of the azimuth servo preamplifier and the elevation servo preamplifier.

These outputs were recorded on a Sanborn paper tape recorder. With the input signal adjusted for 10 db S/N ratio the output error voltage was measured. Then the S/N ratio was successively increased to 20 db, 30 db, etc., to 73 db, and for each S/N the servo preamp error voltage was recorded on the Sanborn recorder.

Table 4.3-6 gives the results for System No. 3 (Serial No. 49) and is representative of the results for all three systems.

Entries in Table 4.3-6 will be explained briefly. For each input S/N the square-wave peak-to-peak error voltage is given for azimuth and elevation. These were values as measured on the Sanborn recorder.

The $\pm$2 db and $\pm$3 db limits listed in the table were calculated from 10-db S/N to 50-db S/N voltage entries in accordance with the performance specification. This was done as follows (using the azimuth error voltages as an example).

From 10 db to 50 db S/N, the azimuth error voltage changed from 8.0 to 10.0 volts. The midpoint between these extremes is 9.0 volts. This is the reference voltage used for calculating the limits.

To find the allowable +2 db upper limit relative to the 9-volt reference, the following simple relationship was used:

$$2 \text{ db} = 20 \log (E_{upper})/9$$

$$E_{upper} = 11.34 \text{ volts} \approx 11.3 \text{ volts in the table.}$$

TABLE 4.3-6

DYNAMIC-RANGE TEST RESULTS
(System No. 3)

S/N Ratio		Azimuth Error V P-P	Elevation Error V P-P
10 db		8.0	12.0
20 db		10.0	11.0
30 db		10.0	10.5
40 db		10.0	10.5
50 db		10.0	9.5
	Limit	+2 db = 11.3 V P-P	+2 db = 13.5 V P-P
	Limit	-2 db = 7.1 V P-P	-2 db = 8.5 V P-P
60 db		10.5	9.0
70 db		11.0	8.5
73 db		10.5	8.0
	Limit	+3 db = 12.7 V P-P	+3 db = 15.2 V P-P
	Limit	-3 db = 6.4 V P-P	-3 db = 7.63 V P-P

Similarly the -2 db lower limit in Table 4.3-6 was found from:

$$2 \text{ db} = 20 \log \frac{9}{E_{lower}}$$

$$E_{lower} = 7.07 \text{ volts} \approx 7.1 \text{ volts per table.}$$

The +3 db and -3 db azimuth voltage limits were computed in the same manner, using 9 volts as the reference. Also the elevation limits were computed in the same manner as the azimuth limits except that the reference voltage (established from the elevation error readings for 10 to 50 db S/N ratios) was 9.5 volts plus 1/2 (12.0-9.5) volts = 10.75 volts.

4.4 ANGLE SERVO TESTS

Subsystem tests of the angle servos included measurements of the following performance parameters for both the azimuth and elevation axes:

1. Acceleration and velocity capability.

2. Determination of the velocity error coefficient (Kv).

3. Bandwidth measurements with the gyro stabilization loops opened and closed.

4. Accuracy with which the pedestal follows the designation inputs.

5. Verification of the pedestal rotational limits, the scan limits, and the pedestal braking ability.

Prior to the start of subsystem tests, the servos were aligned and all the pedestal synchros were properly positioned and zero set.

4.4.1 Acceleration and Velocity

A DC step voltage was inserted as an error signal into the servo loop and the output voltage from the tach generator was recorded. One-second timing pulses on the recorder calibrated the paper speed. The voltage scale of the recorder was calibrated as an analog of the pedestal speed.

The maximum rate of increase of the tach voltage after application of the step error is a measure of the acceleration capability of the servo and the maximum voltage output is a measure of the servo velocity capability. The measured values of angular acceleration and velocity are as follows:

	Angular Acceleration		Velocity	
	Azimuth ($mils/sec^2$)	Elevation ($mils/sec^2$)	Azimuth (mils/sec)	Elevation (mils/sec)
System No. 1	1540	1810	920.0	756.6
System No. 2	1365	1330	821.2	657.0
System No. 3	1314	1839	821.0	788.0

4.4.2 Velocity Error Coefficient

The velocity error coefficients (Kv) were determined by injecting into the servo loops a DC error voltage equivalent to 0.3 mil and clocking the elapsed time for the pedestal to move through 1600 mils (45°). The following formula is used to calculate the velocity error coefficient:

$$Kv = \frac{\text{velocity}}{\text{error}} \text{ or } \frac{1600 \text{ mils/elapsed time}}{0.3 \text{ mil}}$$

The Kv of both elevation and azimuth servos were determined with the wide bandwidth selected and the gyro stabilization loops opened. The results calculated from the test data are:

	Velocity Error Coefficient (Kv)	
	Azimuth (sec^{-1})	Elevation (sec^{-1})
System No. 1	357	328
System No. 2	450	380
System No. 3	293	380

4.4.3 Bandwidth Measurements

With the angle servos locked on the boresight tower signal source, a 0.05-cps sine-wave forcing function was applied to the position loops (first, one axis then the other) and the pedestal response was monitored as the frequency of the forcing function was increased. The bandwidth of the position loop was measured as the frequency at which the pedestal response was 3 db below the level of the input forcing function. Bandwidth measurements were made with the gyro loop opened and closed. The results are listed below:

	Angle Servo Bandwidths			
	Gyro Loop Closed		Gyro Loop Opened	
	Azimuth (cps)	Elevation (cps)	Azimuth (cps)	Elevation (cps)
System No. 1	2.3	2.5	4.4	4.35
System No. 2	2.0	2.0	4.3	4.6
System No. 3	2.3	2.1	4.1	4.1

Bandwidths of the tachometer-loop response were also measured. The test data shows that the tach-loop bandwidth varied from 7.5 to 10.5 cps. The tach-loop measurements were taken with the gyro loop opened.

4.4.4 Designate Accuracy

The purpose of this test was to verify that the pedestal would follow synchro designation commands with a positional error equal to or less than 2.0 mils.

Command signals were supplied by the local designation synchros and the pedestal position was determined by the cursor scales on the pedestal and the console decimal readouts. This test, performed on each of the three systems, demonstrated that the pedestal designation accuracy is well within the specified 2.0 mils of allowable error.

4.4.5 Rotational Limits, Braking, and Scan Limits

A series of go/no-go tests were conducted to verify the pedestal rotational limits, the braking capability, and the scan limits. The test results demonstrated that the pedestal performance satisfactorily met the specified requirements.

4.5 RANGE TRACKER TESTS

The range simulator/exerciser was used as the source for the simulated targets required to test the range tracker. The following paragraphs briefly outline the tests conducted at the subsystem level to verify the performance of the range tracker.

4.5.1 PRF Measurements

The pulse repetition rate of the range tracker was measured at 160, 640 and 1024 PPS with a calibrated pulse counter. The measured PRF's for all three systems were well within the allowable error of $\pm 1\%$.

4.5.2 Maximum Range Capability

A simulated target at about 64,000,000 yards range was inserted into the range tracker. The tracker was commanded (by console pushbutton) to acquire the target using multiple-gate acquisition. After target lock-on was verified by the console indicator (range lock-on lamp lights), the range displayed by the decimal readout on the console was noted. The range measurement for each system exceeded the 64,000,000-yard requirement.

4.5.3 Velocity Memory

This test consisted of inserting a simulated target ($S/N \approx 6$ db) with a range rate of +10 Kyds/sec into the range tracker. After target lock-on, the signal level was reduced by 20 db. The range rate, five seconds after signal loss, was then compared to the initial rate of +10 Kyds/sec. The measured change in velocity, five seconds after signal loss, was +4, +64, and +44 yds/sec for the three systems. The allowable 1% change for a 10-Kyd/sec target is 100 yds/sec.

4.5.4 Coast Capability

The test for coast capability closely parallels the velocity memory test. The simulated target was inserted with +10 Kyds/sec velocity but at a S/N of approximately 50 db. Instead of reducing the signal level (as was done in the velocity memory test), the coast pushbutton on the console was depressed. Five seconds after initiation of the coast command, the measured drift in range velocity was +40, +56, and +74 yds/sec for the three systems. The measured performance of the range servo was, once again, within the specified 1% allowable error.

4.5.5 Manual Range Rate Control

The objective of this test is to verify the limits of the manual range rate control. The measurements taken on the three systems are tabulated below. The specification requirements were met or bettered in every case.

Manual Range Rate Control

	Control Limits (Kyds/sec)	Slew Speed (Kyds/sec)
System No. 1	-48 to +48	-380 and +378
System No. 2	-32 to +32	-268 and +268
System No. 3	-34 to +30	-290 and +254
Specified requirement	-30 to +30	-240 and +240

4.5.6 Beacon Delay Adjustment

In order to compensate for different beacon delays, fine and coarse adjustments are provided on the range control panel (Cabinet 123 A1) to vary the delay between the skin and beacon tracking gates. The adjustment range of these controls was measured, and the results are presented below.

	Beacon Delay Adjustment (Microseconds)
System No. 1	-0.3 to 10.0
System No. 2	0.0 to 10.0
System No. 3	0.0 to 10.0
Specified requirement	$0\,^{+0}_{-0.5}$ to 9.9 (minimum)

4.5.7 Power Programmer

The instrument servo controlling the setting of the power programmer was exercised in each of the four selectable ranges. For example, the range tracker was designated to 1 Kyd and it was noted that the attenuator was driven to the maximum-attenuation position. The range tracker was then designated to 128 Kyds and it was noted that the attenuator was driven to the minimum-attenuation position. This exercise was repeated for each of the four selectable ranges: 1-128 Kyds, 2-256 Kyds, 4-512 Kyds, and 8-1024 Kyds. The power programmer was also manually commanded by the console control to its maximum and minimum positions. Automatic and manual operation of the power programmer in each system was successfully demonstrated.

4.5.8 Multiple-Gate Detection and Ambiguity Resolution

The objective of this test is to demonstrate the ability of the range tracker to acquire a target using multiple range gates and to resolve range ambiguity. The range tracker was initially positioned to a range of 60 miles. A simulated target (S/N of 10 db) at 1396 miles with an incoming velocity of 6,000 yds/sec was permitted to enter the multiple-range-gate region. The test was considered to be successfully completed if the range tracker acquired the simulated target (RANGE LOCK-ON lamp became illuminated) and resolved the range ambiguity (UNVERIFIED lamp became extinguished).

4.5.9 Range Tracking Performance

The range tracking performance of each of the systems was verified by determining that the ADRAN tracker would continue tracking a moving (20 Kyd/sec) simulated target through two zones as the S/N was reduced from 20 to 6 db.

4.5.10 Auxtrack

The performance of the auxtrack portion of the range tracker was verified by determining that the auxtrack circuits could acquire a simulated target (velocity of 5 Kyds/sec) in the full range and interval gate operation. The ability of auxtrack to supply range designation data to ADRAN was also verified.

4.5.11 Automatic Transmitter Phasing

The ADRAN tracker was locked on a stationary target, AUTO XMTR PHASING was selected at the console, and a moving target was inserted in the video channel.

Selection of AUTO XMTR PHASING produced the early and late guard gates on either side of the range tracking gate. It was further noted that as the moving target entered either guard gate, the ADRAN tracker rephased the mod trigger and the range gate to prevent the moving target from entering the range gate.

4.6 DATA HANDLING

Tests of the data-handling subsystem can be divided into three groups: (1) tests of the linearity with which antenna azimuth and elevation position data is generated and processed, (2) tests of radar response to simulated binary signals from the computer, and (3) tests of the ability of the radar to generate appropriate binary signals for the computer.

4.6.1 Azimuth and Elevation Data Linearity

This test checked simultaneously the linearity of the following portions of the data-handling subsystem.

(a) The circuitry and devices which generate binary signals representing current antenna-pedestal azimuth angle and elevation angle.

(b) The circuitry and devices which decode such binary signals and drive numeric readouts at the operating console showing pedestal azimuth and elevation angles.

The test was performed for azimuth and for elevation separately. In the azimuth test the pedestal was positioned every 20 degrees of azimuth over one complete rotation, and at each position the console numeric indicators of antenna azimuth were checked. This was performed with the antenna rotating in both directions; i.e., first the antenna was rotated clockwise in azimuth stopping every 20 degrees to check the console numeric readings; then the antenna was rotated counterclockwise in azimuth stopping every 20 degrees to check the readings. Taking readings in both directions of pedestal rotation enabled discovery of the effects of factors such as backlash on linearity.

In elevation the antenna was elevated from zero degrees (horizontal) through 90 degrees (zenith) to 180 degrees (fully plunged) stopping every 22.5 degrees to check the console indicator readings. This test too, was performed in both directions.

The circuit functions tested are evident in Figure 3.9-1, which appears earlier in this report. The situation for the test would be that existing if the "tangent-plane/deck-plane" switch in the diagram were in the "deck plane" position. The test verified the linearity of the following functions, shown as blocks in Figure 3.9-1.

(a) The Gray-code mechanical and optical encoders in the "antenna" block.

(b) The two blocks (one for azimuth, one for elevation) which: (1) perform Gray-to-binary conversion, (2) correct ambiguity between the mechanical and optical encoded data, and (3) form the binary words for use by the computer and, if desired, by the operator console.

(c) The connections of azimuth and elevation binary data through the "tangent-plane/deck-plane" switch.

(d) The "display register" blocks for azimuth and elevation binary data, the binary-to-BCD converter, and the "display driver" blocks which appropriately actuate the console decimal displays.

Results of the azimuth linearity test are presented in Table 4.6-1. This represents data from System Serial No. 47. The other two systems gave equally good results as explained below. First however, the entries in the table will be briefly explained.

Note that the table has two sets of entries, one for clockwise, and the other for counterclockwise rotation as mentioned above. Under the clockwise set, the first column represents degrees of azimuth, and the first column entry (zero) represents zero degrees of azimuth as reached by clockwise rotation (actually by rotation from about 350° toward zero). This zero reading was measured by noting the mechanical scale on the pedestal but was set with more precision by using an electrical null in the 36-speed synchro geared to the pedestal drive. This synchro, which is independent of the system being tested, exhibits two nulls per turn, and, being geared at 36 times the pedestal azimuth rotation, furnishes precisely four nulls per 20-degree step of azimuth rotation used in the test.

The second column in Table 4.6-1 simply converts azimuth in degrees to azimuth in angular mils. The third column shows the azimuth as read at the console, and the last column shows the error of the console indications from pedestal position.

The "resultant linearity error" at the bottom of the table is the rms deviation of the 37 errors from the average error. Its value of 0.075 is well within the 0.1 mil allowed by specification.

The table shows data for System Serial No. 47. The other two systems gave similar results; System Serial 48 exhibited an rms error of 0.06 mil and Serial 49 gave 0.08 mil.

The test of elevation data linearity was performed in a manner which was exactly analogous to the azimuth test. Results obtained for System Serial No. 47 are shown in Table 4.6-2. The rms deviation of 0.04 mil is well within the 0.1 mil allowed; this was also true of Systems 48 and 49. System 48 gave zero mil rms error, and Serial 49 gave 0.05 mil rms.

4.6.2 Use of Computer Simulator in Data Handling Tests

Tests of the data handling subsystem were performed through the use of a computer simulator which furnished digital designations similar to those from the ship's CDP and which accepted and displayed (by lamps) digital

TABLE 4.6-1

AZIMUTH DATA LINEARITY FOR SYSTEM SERIAL NO. 47

Clockwise Pedestal Rotation			
Azimuth Pedestal Position (Degrees)	Azimuth Pedestal Position (Mils)	Console Azimuth (Mils)	Readout Deviation (Mils)
0	0000.0	0000.1	+.1
20	0355.5	0355.6	+.1
40	0711.1	0711.15	+.05
60	1066.6	1066.7	+.1
80	1422.2	1422.2	0
100	1777.7	1777.8	+.1
120	2133.3	2133.4	+.1
140	2488.8	2488.9	+.1
160	2844.4	2844.5	+.1
180	3200.0	3200.0	0
200	3555.5	3555.6	+.1
220	3911.1	3911.2	+.1
240	4266.6	4266.6	0
260	4622.2	4622.2	0
280	4977.7	4977.8	+.1
300	5333.3	5333.3	0
320	5688.8	5688.9	+.1
340	6044.4	6044.5	+.1
360	6400.0	0000.1	+.1

Counter-clockwise Pedestal Rotation			
Azimuth Pedestal Position (Degrees)	Azimuth Pedestal Position (Mils)	Console Azimuth (Mils)	Readout Deviation (Mils)
340	6044.4	6044.3	+.1
320	5688.0	5688.7	-.1
300	5333.3	5333.2	-.1
280	4977.7	4977.6	-.1
260	4622.2	4622.0	-.2
240	4266.6	4266.5	-.1
220	3911.1	3911.05	-.05
200	3555.5	3555.4	-.1
180	3200.0	3199.9	-.1
160	2844.4	2844.3	-.1
140	2488.8	2488.8	0
120	2133.3	2133.2	-.1
100	1777.7	1777.6	-.1
80	1422.2	1422.1	-.1
60	1066.6	1066.6	0
40	0711.1	0711.0	-.1
20	0355.5	0355.4	-.1
0	0000.0	6399.9	-.1

Resultant Linearity Error 0.075

TABLE 4.6-2

ELEVATION DATA LINEARITY FOR SYSTEM SERIAL NO. 47

UPWARD (HORIZONTAL TO PLUNGED HORIZONTAL)				DOWNWARD			
Elevation Pedestal Position (Degrees)	Elevation Pedestal Position (Mils)	Console Elevation Readout (Mils)	Readout Deviation (Mils)	Elevation Pedestal Position (Degrees)	Elevation Pedestal Position (Mils)	Console Elevation Readout (Mils)	Readout Deviation (Mils)
0	0000.0	0000.0	0	180	3200.0	3199.9	-.1
22.5	0400.0	400.0	0	157.5	2800.0	2799.9	-.1
45	0800.0	800.0	0	135	2400.0	2399.9	-.1
67.5	1200.0	1200.0	0	112.5	2000.0	2000.0	0
90	1600.0	1600.0	0	90	1600.0	1600.0	0
112.5	2000.0	2000.0	0	67.5	1200.0	1200.0	0
135	2400.0	2400.0	0	45	0800.0	0800.0	0
157.5	2800.0	2800.0	0	22.5	0400.0	0400.0	0
180	3200.0	3199.9	-.1	0	0000.0	0000.0	0

Resultant Linearity Error (Mils) 0.04

position data from the radar. The simulator was used to test the response of the radar to computer binary signals as follows:

(a) Designation of the radar to a specific azimuth.

(b) Designation to a specific elevation.

(c) Insertion of feed-forward correction signals (to correct for ship's attitude).

(d) Deflection commands to the console C-scope (which is an azimuth-vs-elevation display with targets appearing on the display as Z-axis (intensity modulated) signals.

(e) Signals representing target azimuth, elevation, and range rate, which the radar must convert from binary signals to decimal indications on the numeric readouts at the operator's console.

In addition to simulating computer-to-radar signals, the simulator was also used to display and measure radar-to-computer binary signals as follows:

(a) Signals representing pedestal azimuth.

(b) Signals representing antenna elevation angle.

(c) Azimuth and elevation offsets (joystick).

(d) Azimuth and elevation errors and AGC signals.

(e) Identification words.

(f) Range.

Since the computer simulator is basic to all the above tests, it is described first.

4.6.2.1 Computer Simulator

The computer simulator is a piece of special test equipment designed to simulate independently many of the functions of the ship's CDP for use in testing the operation of the radar. Figure 4.6-1 is a functional diagram of the computer simulator.

The front panel of the simulator contains 25 toggle switches, 25 indicating lamps, and three rotary switches. One rotary switch is utilized to select the radar strobe rate (10, 20, or 40 pps). The 25 toggle switches are used to simulate a computer data word which is used as an input to the radar for the function selected on the "Data Out" rotary switch. In the "Az Des" or "EL Des" positions, the pedestal position is compared against the toggle switch inputs, utilizing the simulator's built-in adder circuit, and the

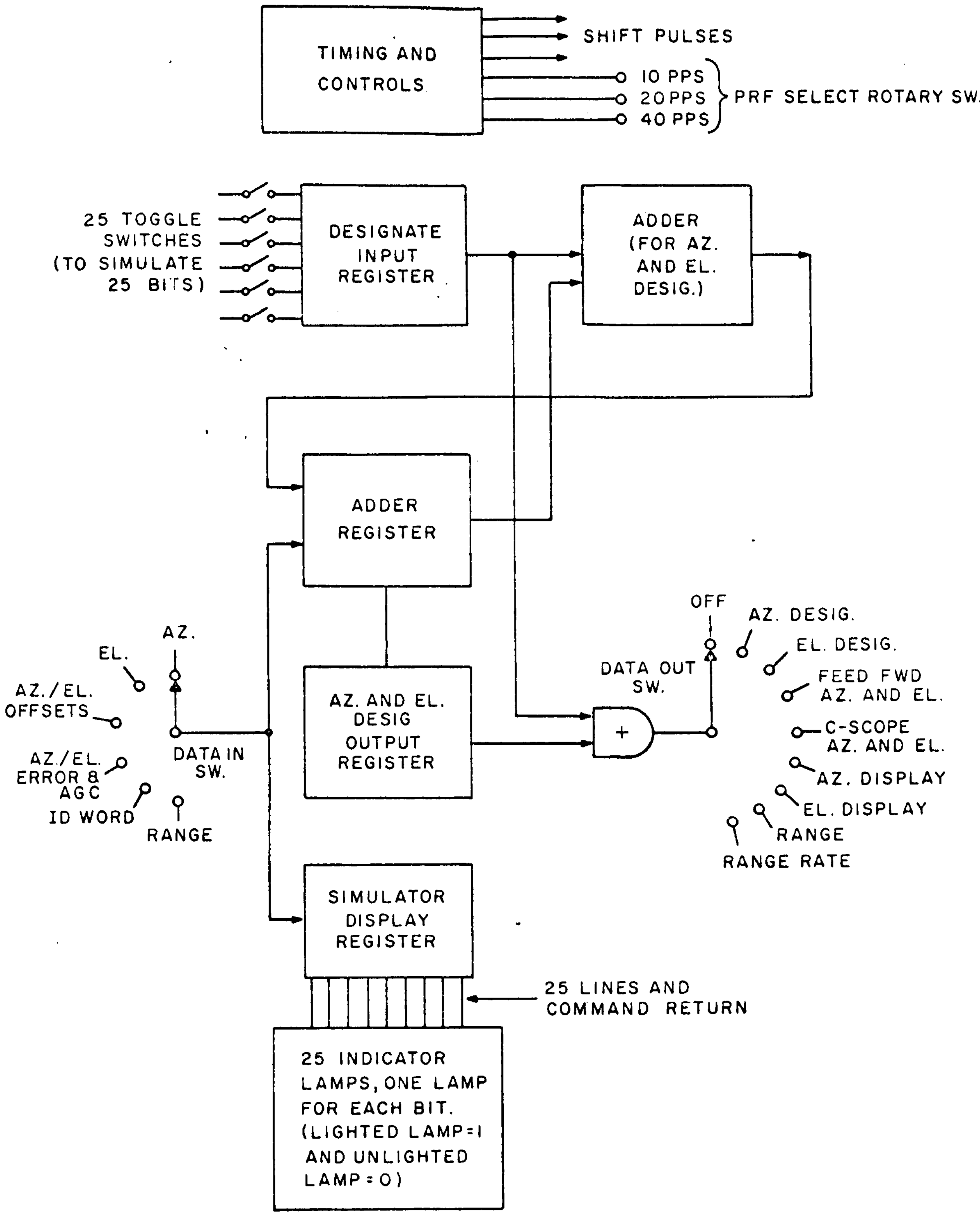


Figure 4.6-1. ASIR Computer Simulator

error signal is generated to designate the radar. The remaining positions on the "Data Out" switch simply use the toggle switch positions to generate a binary word that can be used to test the feed-forward azimuth and elevation digital-to-analog converters, the azimuth and elevation C-scope circuits and to test the console display circuits. The third rotary switch on the panel is the "Data In" switch which is used to select a particular input word from the radar to the simulator and display it as a binary word on the 25 indicating lamps on the panel.

In addition the computer simulator contains controls to generate the proper radar strobe (10, 20, or 40 pps), generate the necessary delays, and to generate the 25 pulses required for shifting-radar data into the simulator and for shifting computer information out to the radar.

4.6.3 Azimuth and Elevation Digital Designation

For this test the radar was placed in the manual control mode, and the antenna was manually positioned to zero mils azimuth. The computer simulator (described above) was then adjusted as follows:

(a) The DATA OUT rotary switch was turned to the AZ DESIG position.

(b) The 25 simulated bit toggle switches were adjusted so that the switch representing bit number 10 was closed (to give a digital "one"), and all other toggle switches were open. This represented an azimuth designation angle of 1600 mils, i.e., 90 degrees.

With the computer simulator thus adjusted to furnish a 90-degree designation, the COMPUTER pushbutton at the radar console was depressed, thus accepting the designation from the computer simulator. The antenna immediately slewed in azimuth and stopped at the designated 1600-mil designated azimuth within the prescribed ± 2.0 mils tolerance. Results for all three radars tested are given in Table 4.6-3.

TABLE 4.6-3

AZIMUTH DIGITAL DESIGNATION TEST RESULTS

System No.	Orig. Ped. Azimuth	Digital Az. Desig.	Resulting Ped. Az (mils)	Deviation from Desig. Azimuth
1	0 mils	1600 mils	1599.8	-0.2 mil
2	0 mils	1600 mils	1599.5	-0.5 mil
3	0 mils	1600 mils	1600.1	+0.1 mil

The elevation designation was tested in a similar fashion. From zero mils (horizontal) the antenna was designated by simulated computer signal to 800 mils or 45 degrees elevation. The antenna slewed to the designated elevation and stopped within the prescribed tolerance of ±2.0 mils as shown in Table 4.6-4.

TABLE 4.6-4

ELEVATION DIGITAL DESIGNATION TEST RESULTS

System No.	Orig. Ped. Azimuth	Digital Az. Desig.	Resulting Ped. Az (mils)	Deviation from Desig. Azimuth
1	0 mils	800 mils	800.1	+0.1 mil
2	0 mils	800 mils	800.7	+0.7 mil
3	0 mils	800 mils	800.0	zero mil

4.6.4 Stabilization Input Signals to Radar

For this test the computer simulator was adjusted as follows: The DATA OUT rotary switch was put in the FEED FWD AZ and EL position, and toggle switches numbers 6 through 15 and 16 through 25 were closed to give nine-bit "ones" for the elevation and azimuth feedforward words respectively. Resulting feedforward correction signals of 5 volts DC were measured in the angle bank of Cabinet 119. This test was successfully performed for all three radars.

4.6.5 Deflection Commands to C-Scope

The DATA OUT switch in the computer simulator was turned to the C-Scope AZ and EL position, and 8-bit deflection signals for azimuth and for elevation were generated by closing the appropriate toggle switches. The C-scope display on the operator's console exhibited corresponding deflections. This test was performed for all three radars.

4.6.6 Azimuth Display Inputs to Radar

The DATA OUT rotary switch on the computer simulator, Figure 4.6-1, was turned to the AZ DISPLAY position and toggle switches 9 through 25 out of the 25 toggle switches used to generate 17-bit display command words. These 17 switches were successively adjusted to furnish eleven different 17-bit binary signals covering azimuths from zero to 6012.3 mils. For each of the eleven combinations the azimuth readout indicators on the operator's console formed the corresponding reading. This was performed for all three radars.

4.6.7 Elevation Display Inputs to Radar

The console elevation readouts were tested in the same manner as just described for the azimuth indicators. Response of the elevation readouts to the 17-bit digital commands was demonstrated at eleven different elevations including negative (antenna depressed) readings.

4.6.8 Range Rate Display Inputs to Radar

The range rate readouts were tested in the same manner as the azimuth and elevation readouts just described. Digital commands were simulated for approaching and for receding targets with range rates between zero and 31,998 yards per second. Twelve different digital commands were thus simulated and for each command, the console range rate readouts responded accordingly.

4.6.9 Radar Generation of Azimuth Position Signals

All the above described tests using the computer simulator were tests of the response of the radar to simulated computer signals. The simulator was also used to demonstrate that the radar also furnished appropriate signals to the computer. Azimuth position was tested first. The DATA OUT rotary switch on the simulator (Figure 4.6-1) was turned to the OFF position, and the DATA IN rotary switch was turned to the AZ position. The PRF SELECT rotary switch was set to 40 pps; this established the rate at which the simulator sampled the azimuth data from the radar. This azimuth data appeared as 17-bit binary signals representing the pedestal position. (In the signals, the 17th bit represents 3200 mils, and the least significant bit represents $6400/2^{17} = 0.0488$ mils.)

The simulator, as shown in Figure 4.6-1, allows direct display of these signals on 17 of the 25 indicator lamps, one for each bit. A lighted lamp means that its corresponding bit is carrying a "1"; an unlighted lamp means that its corresponding bit is carrying a "zero".

The radar was placed in the local (console) mode, and the pedestal was set to 4266.6 $\pm$ .1 mils azimuth. The lamps in the computer simulator exhibited the appropriate 17-bit binary azimuth signal within a tolerance of six least-significant-bit quanta (i.e., 6 x 0.0488).

At the same time the voltage level for the "zeroes" and "ones" was measured with results as shown, for all three radars, in the first line (Azimuth) of Table 4.6-5.

4.6.10 Radar Generation of Other Binary Signals

In addition to azimuth binary signals, the radar was made to furnish other binary signals as shown in Table 4.6-5 and as briefly summarized below.

(a) Elevation Signals (line 2 of the table) were generated and tested in the same manner as the azimuth signals just described.

TABLE 4.6-5

MEASURED VOLTAGE LEVELS OF "ZERO" AND "ONE" BINARY BITS IN DATA OUTPUT SIGNALS FROM ASIR RADARS

Data Output Signal	No. of Bits	Measured Level in Volts* System No. 1 Zero	One	System No. 2 Zero	One	System No. 3 Zero	One
Azimuth	17	0	9.0	0	9.0	0	9.0
Elevation	17	0	9.0	0	9.0	0	9.0
Az & El Offsets	8-8	0	9.0	0	9.2	0	8.4
Range	25	0.25	9.1	0	8.0	0	9.0
AGC, Az & El Lag	8-8-8	0	9.0	0	9.0	0	9.0
Ident.	1 to 3	0	9.0	0.2	9.5	0	8.2

*Allowable voltage limits are between -0.5 volts and +0.5 volts for the "zero" level and between 7.0 volts and 10.0 volts for the "one" level.

(b) Azimuth and Elevation Offsets (line 3 of the table) were generated by moving the joystick up and down, left, and right to generate azimuth and elevation words consisting of 7 bits each plus sign.

(c) Range Signals (line 4 of table) were obtained from the range bank at a reading of 43,690,666 ± 2 yards.

(d) AGC, Azimuth and Elevation Servo Lag Signals (line 5 of table). These were tested by means of a boresight tower. The radar was offset by 1 mil from the tower and the appropriate error signals were generated and noted on the computer simulator.

(e) Identification Words (last line of table). A total of 29 different system conditions were established by depressing console push-buttons and the radar generated the appropriate binary report in each case.

4.7 CONSOLE AND MODE SWITCH TESTS

Most of the console pushbuttons, illuminated indicators, potentiometer controls, decimal readouts and CRT displays were tested during the performance of the other subsystem tests. The remaining controls were exercised and the various subsystems were checked to verify that the console commands were being followed. Circuit checks were performed at the Radar Data Junction Box to verify the DC levels, relay closures, etc., passing through this interface between the radar system and external equipments.

4.8 SYSTEM PERFORMANCE TESTS

The system performance tests can be broadly categorized as follows:

1. Boresight capability.

2. Ranging performance.

3. Tracking precision.

The boresighting capability of each of the systems was measured prior to the sphere track test. Tracking of a balloon-supported sphere provided the data to evaluate the system ranging performance and tracking precision.

4.8.1 Boresight Capability

By utilizing the optical targets on the boresight tower and the Versatel Lens, the following alignments were accomplished:

1. The pointing axis of the Versatel Lens was set orthogonal to the elevation axis, and

2. The Versatel Lens pointing axis was set parallel to the plane of zero elevation.

Once the pointing axis of the Versatel Lens was properly set, the hyperboloidal reflector of the antenna was adjusted using the error-pattern nulls to collimate the RF beam axis with the Versatel Lens axis.

After the alignments and adjustments were completed, collimation and droop errors measurements were repeated five times. The maximum error measurements are tabulated below:

	Collimation Error		
	Azimuth (mils)	Elevation (mils)	Droop Error (mils)
System No. 1	0	+0.025	+0.225
System No. 2	+0.1	+0.05	-0.15
System No. 3	+0.047	-0.075	-0.187
Specified Requirement	$\pm$0.1	$\pm$0.1	$\pm$0.3

4.8.2 Ranging Performance

Prior to the sphere track, the boresight signal source was used to calibrate the receiver AGC. The azimuth and elevation error channels on the analog recorder were also calibrated by offsetting the antenna from the boresight source and recording the angle offsets corresponding with pen displacement (the paper chart was calibrated for increments of 0.5 mil over a range of $\pm$1.25 mils). The range error channel was also calibrated and the power programmer was accurately set for 24 db attenuation.

The ranging performance of each radar system, as determined from the sphere track data, is shown in Figure 4.8-1. The theoretical performance curve was determined by substituting the various parameters in the radar range equation. For calculation convenience, the decibel-form of the equation was used:

$$S/N = (P_t - 24) + 2G + 2\lambda + A_e - 4R - L_t - L_r - BW - NF - L_k$$

where S/N = signal-to-noise ratio at the IF receiver output (db)

P_t = transmitter power (peak) above 1 watt (60 db)

G = antenna gain (46 db)

λ = wavelength referenced to 1 cm (7.4 db)

A_e = effective radar cross-section of the target referenced to 1 m^2 (-17.5 db)

R = target range referenced to 1 nautical mile (db)

L_t = plumbing loss between transmitter and feed (4.0 db)

L_r = plumbing loss between feed and receiver (1.5 db)

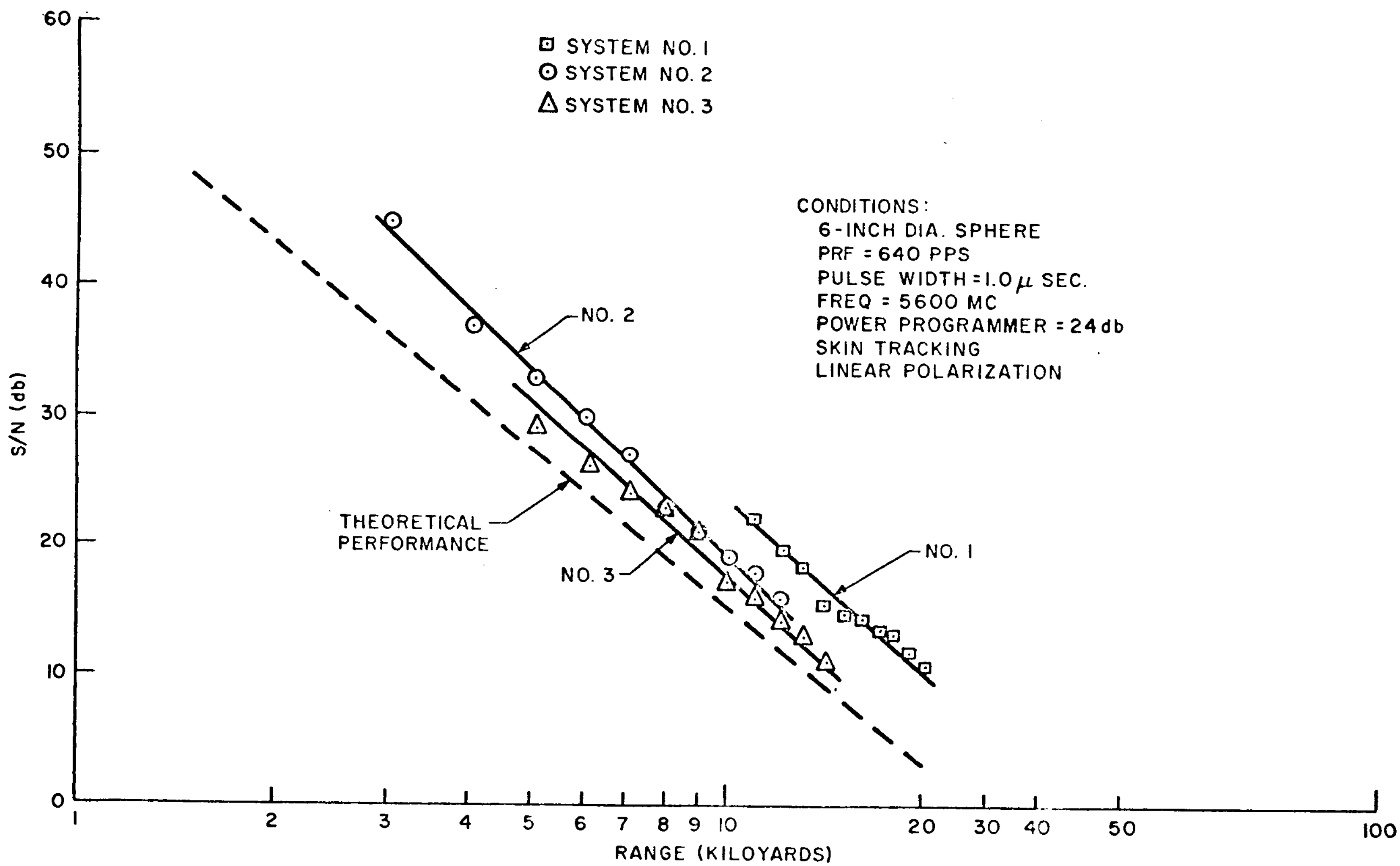


Figure 4.8-1. Ranging Performance of the ASIR Systems

BW = receiver bandwidth referenced to 1 cps (63.0 db)

NF = receiver noise figure (11 db)

L_k = estimated propagation loss (2.5 db)

After substituting the indicated values of the parameter, this equation reduces to

$$S/N = 43.3 - 4R$$

which is plotted in Figure 4.8-1.

At a convenient point during the sphere tracking tests, the polarization of the transmitted energy was switched from linear to circular and then returned to linear. This exercise demonstrated that target tracking could be maintained during polarization switching.

4.8.3 Tracking Precision

During each sphere track, the azimuth, elevation and range errors were recorded for at least 30 seconds when the S/N was 18 db. From the recorded data, the total spread of each error voltage was determined by eliminating approximately 1% of the worst deviations. The total spread was then divided by five to determine the one-sigma value of the random error.

The theoretical justification for this approach lies in the fact that for a Gaussian distribution, 98.76% of the data points will fall within ± 2.5 sigma of the mean value. The summary of results determined by the method described are given below.

	One-sigma Value of the Random Error (S/N = 18 db)		
	Azimuth (mils)	Elevation (mils)	Range (yds)
System No. 1	0.04	0.027	1.0
System No. 2	0.02	0.02	1.0
System No. 3	0.057	0.028	1.3
Specified Requirement	0.1	0.1	3.0